A Critical Investigation into Whole System Transitions to Low Carbon Futures and New Sources of Energy Flexibility in Great Britain's Electricity Sector

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A CRITICAL INVESTIGATION INTO WHOLE SYSTEM TRANSITIONS TO LOW CARBON FUTURES AND NEW SOURCES OF ENERGY FLEXIBILITY IN GREAT BRITAIN'S ELECTRICITY SECTOR

By

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Abstract

Great Britain's (GB) electricity sector is transitioning to low carbon futures in response to various pressures including legally binding carbon emission targets while ensuring security of supply. Such transitions are likely to focus on a mix of inflexible low carbon generation and new sources of energy flexibility, e.g. demand side flexibility, storage and/or interconnection. Existing studies recognise that transitions are uncertain with actors across the whole sector playing a role. However, they suggest tidy and clearly delineated futures and fail to fully capture the messiness emerging from actor interactions. Drawing on transitions research concepts including the Multi-level Perspective, whole system analysis, architectural innovation, power and discourses, this study critically investigates whole system transitions to low carbon futures and new sources of energy flexibility in GB's electricity sector. Data were collected via semi-structured interviews with 28 senior figures across the sector and analysed using thematic coding and discourse analysis.

This study shows that five futures are articulated representing five discourse coalitions (1) 'Market-based', (2) 'Network-focussed', (3) 'Policy-driven', (4) 'Consumer-centric'; and (5) 'Prosumer-led'. These futures are messy because actors hold a plurality of views and cannot be simply marshalled into discourse coalitions. This underscores the complexity of electricity sector transitions and reveals important issues such as different ontologies and framings of energy flexibility. By investigating contemporary energy transition discourses, the study argues that a system level understanding of transitions and changes in future making practices currently dominated by quantitative modelling analyses and fixed transition frameworks are essential to effectively manage transitions. Further research is needed to investigate and find ways to better attend to the messiness and multiplicity of energy transitions from a whole systems perspective. This exploratory study is situated in a broader landscape of transitions research about energy futures and provides useful recommendations for both industry and academic communities.

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Glossary and list of acronyms

Actors	A participant in an action or process. They are individual human beings, organisations or groups whose activities are guided by rules in socio technological systems. Actors also reproduce rules in their activities (Geels, 2004).
Agency	Agency is the ability to take action and make a difference over a course of events. In the transition of socio-technical regime, agency is an ability to intervene and alter the pressure for change and resources in response to change (Smith et al 2005).
Architectural innovation	Involves changes in the linkages of the system components, but the core design concept of each components remains the same (Henderson and Clark, 1990; McMeekin *et al.*, 2019).
BEIS	Department for Business, Energy and Industrial Strategy
Business model innovation	A type of innovation which brings about changes in the way the organisations (1) create and deliver value (2) capture value and (3) change their value propositions (Bocken *et al.*, 2014). Here, value creation and delivery is the most important element as it focuses on how to seize business opportunities and new markets. Value capture includes considering how to earn revenues. Value proposition focuses only on the product and service offering to the market.
CCC	Committee on Climate Change
CCGT	Combined Cycle Gas Turbines – an efficient electricity generation technology from gas (Everett *et al.*, 2012)
CCS	Carbon Capture and Storage – a technology which separated most of the CO_2 and sequestered them under the ground (Boyle, 2012)
CCUS	Carbon capture, usage and storage – a technology which can capture 100% of carbon emissions (BEIS, 2017) and is deployed to reduce carbon emissions from heavy industry (Energy Transitions Commission, 2018)
CEB	Central Electricity Board who was in charge of interconnecting the privately owned power plants from 1926 to 1957 (Everett *et al.*, 2012)
CEGB	Central Electricity Generating Board who owned and coordinated electricity generation in England and Wales from 1957 to 1989 (Everett *et al.*, 2012)
DECC	Department of Energy and Climate Change
DfT	Department for Transport
Discourse	A shared way of apprehending the world (Dryzek, 1997, p.8)
Discourse coalition	A group of actors who share a social construct (Hajer, 1993, p.43)
Dispatchable energy source	A power plant which can be turned on or off to meet electricity demand. Traditional dispatchable energy sources are coal and gas power plants while renewables are non-dispatchable.
DNO	Distribution network operator who owns and operates the distribution network of towers and cables that bring electricity from the national transmission networks to homes and businesses. They do not sell electricity to consumers. In Britain, there are seven distribution network operators including: Scottish and Southern electricity network, Scottish Power Energy Networks, Electricity North West, Northern Powergrid, Western Power Distribution, UK Power Networks and ESB Networks.
DSO	Distribution system operator
DTI	Department of Trade and Industry
Duck curve	The imbalance between solar power generation and electricity demand during a 24-hour day. At noon time, electricity demand is low while solar

	generation is high. At night time, electricity demand is high while solar generation is low.
Electricity security of supply	Balancing electricity supply and demand at all times
Elexon	An organisation which administer the Balancing and Settlement Code (BSC) which defines the rules for the processes of balancing mechanism and settlement. National Grid ensures electricity supply and demand match using a balancing mechanism (i.e. accept volumes from generators and suppliers to increase or reduce their supply/demand). Elexon then manages the settlement, i.e. calculate the differences in actual supply and demand volumes with contracted volumes and enforce payments for these differences).
ENA	Energy Networks Association
EV	Electric Vehicles
GB	Great Britain which refers to England, Scotland and Wales
Generation mix	The percentage of different energy sources (fossil fuels, nuclear, hydro and other renewable energies) used to generate electricity. It is different from energy mix which accounts for the combination of the various primary energy sources used to meet energy needs (electricity generation, housing, transportation) in a given geographic region.
IEA	International Energy Agency
Incremental innovation	Improvements or upgrades of an established technology/product/ service in an existing system/market
Incumbent	Existing actors of an industry
Innovation	A process of finding something new which is different from the existing technology/product/service.
Low carbon generation	A source for electricity generation which releases only low carbon emissions compared to that from a fossil fuel power plant.
Market niche	A segment of a market in which a specific innovation is supported and focused on.
Meaning-making	The process of how persons construe, understand, or make sense of life events, relationships, and the self
Merit order	A way of ranking primary energy sources for electricity generation based on the running cost of the power stations.
Messy	A system of problems that produces dissatisfaction (Ackoff, 1974, p.5)
MLP	Multi-Level Perspective – a framework to study transitions which emphases that transitions come about through the alignment and interaction of dynamics at three different levels: technological niche, socio-technical regime and socio-technical landscape.
Modular innovation	Involves change in a core component of a technology but does not impact the linkages between different components (Henderson and Clark, 1990; McMeekin *et al.*, 2019).
National Grid	A high-voltage transmission network or An organisation who owns the high-voltage transmission networks in England and Wales and operates electricity system. They are responsible for balancing electricity supply and demand second by second. They are separated into National Grid Electricity Transmission (ET) and the Electricity System Operator (ESO) on 1 Apr 2019.
Nationalisation	The process of changing private assets to public ownership of a national government or state

NFFO	Non fossil fuel obligation – one of the UK government's incentives in 1990 to reduce carbon emissions – which first required electricity companies to buy certain amounts of nuclear power from the whole sale markets.
NIC	National Infrastructure Commission
NUM	National Union of Mineworkers - Trade Union representing mineworkers
Ofgem	Great Britain's Office of Gas and Electricity Markets which regulates the energy sector to protect the interest of consumers. It is referred to the regulator.
Primary energy/ electricity sources	The sources which can be used directly to generate electricity such as fossil fuels (coal, gas, oil) or renewables (wind, solar).
Privatisation	A process of selling public assets to the private sector, such as power stations.
Radical innovation	A creation of new technology/product/service which is radically different from established technology/product/service. It may threaten the existence of the established technology/product.
RECs	Regional Electricity Companies which originated from the old nationalised Area Boards.
RIIO model	A regulatory framework to set revenue for network companies. RIIO stands for Revenue = Incentives + Innovation + Outputs. This framework focuses on incentivise network companies to save costs on delivery a network project, to innovate and to deliver outputs meeting consumers' expectation and the needs of a sustainable energy sector (Ofgem, 2010).
Rules	The coordination and structuration of human actors' activities which guides human actors' activities (Geels, 2004)
Societal function	Functions of a society such as electricity supply, transportation, communication, housing, food production (Geels, 2002)
Socio-technical niche	A protected space or incumbent room for radical innovations to develop.
Socio-technical regime	A set of rules which orient and coordinate the activities of the social actors that reproduce the various elements (technology, culture, policy, infrastructure, market, user practice) of socio-technical systems. Elements are aligned and fulfil societal functions.
Socio-technical systems	Includes system components (Technology, user practices, regulation, industrial networks, infrastructure and culture) and the linkages between components necessary to fulfil societal functions
Solar PV	Solar Photovoltaic cells
Sub-system	In the MLP, this refers to science, technology, economy, politics and culture (Geels 2004)
Sunk investment	Investment in assets which costs are sunk. Sunk cost is a cost that has already been committed and cannot be recovered. As such, sunk cost is not taken into short-term business decision making (Mankiw, 2008, p.297)
System integration costs	System integration costs are incurred in the system when low carbon technologies are added to the generation mix, such as an increased balancing cost, necessary reinforcement of transmission and distribution grids, increased backup capacity costs, or the costs of reducing system carbon emissions (Strbac *et al.*, 2015).
The 4Ds	Decarbonisation, Decentralisation, Democratisation and Digitisation
TOTEX	Total expenditure – a concept used in RIIO model which show an allowance for DNOs costs for the regulator to calculate DNOs' base revenue. DNOs are incentivised to spend money on the most cost-effective solution for the network (Ofgem, 2017).

ToU tariff	Time-of-use tariff – an energy tariff where consumers pay different prices for their energy use depending on the time of the days. This tariff is used to incentivise consumers to change their energy demand based on the fluctuation in price.
Trajectory	A particular path that is followed by a particular social group
Transition	A set of processes that lead to a fundamental shift in a system
UKERC	UK Energy Research Centre
Value stacking	Flexibility have a value for different actors, so value of flexibility can be stacked. In other words, flexibility can be monetised concurrently by different actors, or at different times by different actors. Different actors who are able to provide flexibility are able to participate in system operators' balancing market or in wholesale market or DNOs' network constraints market.

CHAPTER 1 INTRODUCTION

This chapter introduces the general background of the study, explains its importance, and sets out the overarching research aim and objectives, research scope, the researcher motivations and the thesis structure.

1.1 RESEARCH CONTEXT

Over the 100 years since Thomas Edison invented the first commercial light bulb in 1879 (Everett *et al.*, 2012), electricity has become an essential utility and involved in almost every aspect of human life, especially in developed countries such as Great Britain (GB). Electricity is widely used not only for essential needs such as lighting, cooking and heating, but also for telecommunications, computers, transportation and in the manufacturing industry (Everett *et al.*, 2012).

In Britain, the electricity sector has been developed with large and centralised fossil fuel power stations. However, many international and national binding agreements (e.g. the Kyoto Protocol (UNFCCC, 1997), the Climate Change Act (UK Government, 2008), the Net Zero target (BEIS, 2019b)) and increasing concerns about climate change in general (i.e. decarbonisation) have gradually influenced its development and potentially changed the generation mix from fossil fuels to low carbon sources such as nuclear power and renewables. Although contributing to the reduction of carbon emissions, these low carbon sources are characterised by inflexibility and intermittency. Nuclear power is inflexible because it needs 24-36 hours to reach its full efficient capacity from starting up and are difficult to turn off (Everett *et al.*, 2012). Renewables including wind and solar power are intermittent in the sense that wind does not blow when we need it and the sun shines more in summer than in winter, while we, conventionally, need more electricity in winter than in summer. In other words, wind and solar power make "*time-variable*" contributions to "*time-variable*" demand (Boyle, 2012). Such inflexibility and intermittency threaten the current level of flexibility in the electricity system and affect electricity security of supply. In a future dominated by low carbon sources of electricity, sources and levels of flexibility are a key concern as rapid and responsive start-up of the existing fossil-fuel generators are phased out.

In addition to decarbonisation, changes in the sector have been shaped by decentralisation, digitisation and democratisation (the so-called 4Ds). Low carbon sources are located nearer the point of consumption and connect directly to distribution grids instead of being transmitted to the point of consumption from a centralised generation location (Watson and Devine-Wright, 2011). Many new digitised technologies have been developed such as smart meters and smart grids which enable effective management in domestic home and at grid level (Wolfe, 2008). These changes towards decentralisation and digitisation facilitate democratisation where consumers may become prosumers and get involved in both electricity generation and consumption (The European Federation of Renewable Energy Cooperatives - REScoop, 2015; Morris and Jungjohann, 2016).

The UK Government frames changes to low carbon electricity systems as a "*transition*" (BEIS, 2017). This transition does not happen easily because of lock-in to existing infrastructure (e.g. the national grid, existing fossil fuel power stations) or to the way that the sector is operating as a centralised top-down network management (Unruh, 2000; Rydin *et al.*, 2012). Therefore, many aspects of the electricity sector will need to change in a transition towards a low carbon future. Transitions are likely to involve not only technologies but also "socio-technical" (Geels, 2002) (i.e. changes in markets, user practices, policy and cultural meanings). However, much research on transitions steer the focus of transitions towards changes in technologies such as solar PVs (Smith *et al.*, 2014), off-shore winds (Kern *et al.*, 2014), nuclear power (Sepulveda, 2016) and electric vehicles (Energy Systems Catapult, 2020) rather than societal aspects and consequently overlook how transitions to low carbon futures and new sources of energy flexibility in GB's electricity may unfold in practice.

Actors with their interests and motivations play an important role in engendering transitions (Geels and Verhees, 2011; Foxon, 2013; McMeekin *et al.*, 2019; Geels *et al.*, 2020; Rogge *et al.*, 2020). Different interests frame energy transitions differently leading to different future pathways or scenarios. Actors with conflicting interests also enter discursive struggles to influence political and economic contexts of transitions.

Moreover, GB's electricity sectors forms "*one large, integrated socio-technical system*" (McMeekin *et al.*, 2019, p.1217). For example, changes in generation (increases in low carbon generation) and changes in consumptions (increases in electricity demand) may threaten transmission/distribution or the need to be in balance of the electricity grid. Therefore, transitions to low carbon futures of the sector require changes along the entire generation, distribution and consumption sub-systems, i.e. of the whole system. This study sits in this broader context of transitions research which focusses on actors' interests and whole system analysis to investigate transitions to low carbon futures and energy flexibility in GB's electricity sector.

1.2 THE SIGNIFICANCE OF THE STUDY

Understanding how transitions in GB's electricity sector may unfold and consequently realising different futures of the sector are increasingly important. These understandings about futures are needed for almost all organisations and societies to "*guide what to do in the present*" (Urry, 2016, p.1). However, research on transitions of the sector in academia mainly focusses on historical transitions via documentary analysis, often with little recourse to industry (e.g. Geels *et al.*, 2016; McMeekin *et al.*, 2019). Such an approach to studying transitions while contributing to the understanding of transitions does not account for prevailing discussions and current changes in electricity sectors and consequently, provides limited insights on low carbon futures. In contrast, this study is funded and supported by the Open University and CGI - an international business management consultant firm, and an industrial supervisor who helps the researcher access to senior figures from GB's electricity sector (e.g. policy makers, senior executives, leaders and advisors). Access to the upper echelons of the electricity sector enabled the researcher to gain valuable insights of the industry and to develop an understanding of how transitions to low carbon futures actually unfold. This study, therefore, focusses on transitions to low carbon futures with discussions and commentaries from senior figures, and significantly addresses the needs to further understand whole system transitions and the attainment of lower carbon futures.

This study also plays an important role in rethinking future making practices in the electricity sector. Within the sector, many future scenarios are published by varieties of industrial actors (ENA, 2018; National Grid, 2018; 2019b; Energy UK, 2019). For example, National Grid, publishes Energy Future Scenarios every year to "*help the industry to focus on how we could efficiently transition to a low carbon economy*" (2018) and to "*continue supporting the development of the energy system that is robust against different outcomes*" (2019b). However, these industrial publications predominantly develop futures by modelling tasks with pre-defined timeframes, dominant technologies and fixed planning objectives. These may undermine the actual processes of transitions which involve power and discursive struggles of actors, i.e. which ultimately be uncertain and messy. Deviating from such dominant future making practice, this study constructs futures using the notion of discourse coalitions. In this study, discourse coalition is a group of actors who share similar sets of assumptions about how transitions to futures come about but hold different interests and motivation (Hajer, 1993). Futures articulated from discourse coalitions are able to reflect the actual transition processes and capture the uncertainty and messiness of futures emerging from interactions of actors. Hence, this study not only reflects how transitions actually unfold but also facilitates the industry and the government in developing appropriate transition management strategies and energy policy.

1.3 RESEARCH AIM AND OBJECTIVES

To understand whole system transitions to low carbon futures and to rethink future making practices of the sector, the literature will be reviewed to detail gaps in knowledge and research approaches (see details in Chapter 2). Research aim and objectives will then be articulated. The final set are as follows:

Research aim: To critically investigate whole system transitions to low carbon futures and new sources of energy flexibility in GB's electricity sector.

Research objectives:

- To identify dominant energy discourse coalitions within GB's electricity sector.
- To identify futures of GB's electricity sector, focussing on whole system analysis.
- To identify how transitions to new sources of energy flexibility may be achieved in each future.

1.4 RESEARCH SCOPE

Many future scenarios focus on the whole system analysis which comprises of electricity, gas, heat and transport (e.g. Energy UK, 2016; National Grid, 2019b) However, this study focusses on the electricity sector itself. It is relevant in the sense that the electrification of heat and transport to reduce carbon emissions in these areas, will increase the demand for electricity (CCC, 2017). There is a need to change the whole electricity sector (spanning from generation, distribution and consumption) to accommodate increased electricity demand and ensure electricity security of supply.

This study focuses on Great Britain's (GB) electricity sector, rather than the whole of the United Kingdom's (UK) electricity sector (which includes Great Britain and Northern Ireland). At the moment, the electricity sector is regulated by *Ofgem* which is GB Office of Gas and Electricity Markets (Ofgem, 2020a). Therefore, from a regulatory perspective, Great Britain's electricity sector is the relevant unit of analysis.

Transitions of the sector emerge through the interactions of industrial actors discussing and negotiating futures. Seen in this way, the industry has considerable power to accelerate transitions to a low carbon future. Therefore, this study pays attention to various key industrial actors such as Ofgem, National Grid, Distributions Network Operators (DNOs), suppliers and generators.

This study investigates transitions to different futures of the sector. The term "futures" is used, instead of future pathways or scenarios. Future pathways and scenarios seem to imply the common future making practices by quantitative modelling analyses. As this study uses qualitative methods, the researcher avoids such connotations.

The researcher does not set a specific time horizon for this study because futures are open-ended and contingent. This will open a chance for interviewees to comment on appropriate timescales for transitions to unfold.

1.5 THE RESEARCHER

Subjectivity cannot be avoided in qualitative research. As such, the researcher forms an important part of the research process and it is useful to describe the researcher's background and motivations.

The researcher was born and lived in Hanoi, the capital of Vietnam before coming to the UK to pursue further education. Hanoi is a crowded city where the Government, many embassies, universities and companies are located. However, electricity has been cut regularly in each district. The researcher has experienced heat at 36 Celsius without any electricity many times. Therefore, the researcher is, in the long term beyond this PhD, motivated to explore how transitions to low carbon futures of GB's electricity sector can be adapted in Vietnam context to assist Vietnam moving towards a sustainable energy system in the future.

Before pursing this PhD, the researcher obtained a Bachelor Degree in International Relations, major in International Economics at the Diplomatic Academy of Vietnam in 2009 and a Master of Science in Management at the University of Glasgow, United Kingdom in 2010. These degrees facilitated her with knowledge in economics, sociology, organisational culture, academic writing and so on. These experiences and studies 'set the stage' for the PhD.

1.6 THESIS STRUCTURE

This introduction chapter is followed by six chapters.

<u>Chapter 2 – Literature review</u>

This chapter reviews literature on the development of GB's electricity sector where the objectives of ensuring electricity security of supply and decarbonisation at lowest cost are embedded. Key landmarks of the development from the establishment of the Grid to the so-called 4Ds (Decarbonisation, decentralisation, digitisation and democratisation) are highlighted. Within this context, three gaps in knowledge are identified.

The change of GB's electricity sector to low carbon future is conceptualised as a transition. Hence, this chapter also reviews a number of approaches in transitions research to address the gaps in knowledge. They are the MLP, architectural innovation, power and discourses in transitions. Research aim and objectives are then articulated. Finally, an analytical framework for energy discourse analysis and some contemporary energy discourses to be used for data analysis are identified.

Chapter 3 - Methods

This chapter sets out the methods chosen to conduct the study. It is divided into two sections. The first section identifies and reviews methods to meet the research aim and objectives. The second section articulates how the chosen methods were actually used.

This study follows a flexible design where theoretical frameworks are not fixed. The study was developed via an iterative process where the tasks of reviewing literature, collecting data and analysing qualitative data are intertwined and gradually refined during the process of the study. This research process is conceptualised as a '*progressive funnel*' through which the study gradually became increasingly focussed.

Chapter 4 – Making sense of transitions of GB's electricity sector: a thematic analysis

This chapter focuses on interviewees' assumptions about transitions of GB's electricity sector, including five main themes: (1) Change, (2) Timeframe and nature of change, (3) Stability, (4) Regulation and policy and (5) Goals of transition.

At the end of this chapter, seven dominant discourse coalitions are set out, adapted from the above themes and contemporary energy discourses identified from literature. They are: (1) Economic rationalism, (2) Administrative rationalism, (3) Ecological modernisation, (4) Consumer sovereignty, (5) Energy democracy, (6) Technology focus and (7) Energy flexibility.

Chapter 5 – Futures of GB's electricity sector

This chapter identifies different futures of GB's electricity sector, each of which is rhetorically constructed by discourse coalitions identified in Chapter 4.

(1) Economic rationalism: a 'Market-based' future.
(2) Administrative rationalism: a 'Network-focussed' future.
(3) Ecological modernisation: a 'Policy-driven' future.
(4) Consumer sovereignty: a 'Consumer-centric' future; and
(5) Energy democracy: a 'Prosumer-led' future.

The last two discourse coalitions, technology focus and energy flexibility discourses are accepted among almost all interviewees and are embedded in all futures.

Each future is described in terms of (1) System components, (2) System relationships, (3) Power, and (4) The metaphor of energy flexibility.

<u>Chapter 6 – Discussion</u>

This chapter compares and contrasts the findings from the empirical data from interviews with the literature. Firstly, a critical reflection on futures of GB's electricity sector, how these futures may be realised and the feasibility of these futures are provided. A discussion on ontology and rethinking future making practices are also presented. Next, the chapter provides some theoretical critical reflections on the MLP, architectural innovation, whole system analysis, discourse and power in transitions. Finally, the chapter discusses how to realise energy flexibility.

<u>Chapter 7 – Conclusions and recommendations</u>

This chapter reviews the aim and objectives set out in chapter 1 and 2. It then provides a methodological reflection. After that, it presents the key findings and conclusions of the study. This chapter also identifies the limitation of this study. This chapter ends by providing implications for the industry and recommendations for future research.

CHAPTER 2 LITERATURE REVIEW

2.1 INTRODUCTION

This chapter reviews the transitions of GB's electricity sector to tackle climate changes while ensuring electricity security of supply and examines the role of energy flexibility in these transitions. Three gaps in knowledge relating to the whole sector's transitions to low carbon futures and new sources of energy flexibility (demand side flexibility, storage and interconnection) are identified. In order to address these research gaps, a number of approaches are justified including the MLP, architectural innovation, power and discourses in transitions. The main concepts from these approaches are found useful in enriching the understanding of whole system transitions of the sector. Taking into account these identified research gaps and research approaches, the research aim and objectives of the study are clearly articulated. Analytical frameworks to be used in data analysis are then set out to address these research aim and objectives.

2.2 GREAT BRITAIN'S ELECTRICITY SECTOR

In June 2019, the Government passed legislation to bind the UK to Net Zero emissions by 2050 from the 1990s level (BEIS, 2019b). In 2019, Great Britain also recorded the first coal-free generation week (National Grid, 2019a). Government statistics on 2019 also acknowledged increases in renewables' share of electricity generation to 33% in 2018, from 2.6% in 2000 (BEIS, 2020a). This change can also be seen in GB's landscape, where large cooling towers have been replaced by wind farms and solar panels. It is therefore important to understand a full picture of what and how GB's electricity sector has changed and the implications for the future. This section focuses on two main themes: (1) ensuring electricity security of supply and (2) the historical and current background of GB's electricity sector with key landmarks in policy: from the decision to construct the national grid, to nationalisation, to privatisation and to the current context with the focus on decarbonisation, decentralisation, digitisation and democratisation.

2.2.1 Ensuring electricity security of supply

Ensuring electricity security of supply to 'keep Britain's lights on' has always been one of the key objectives of the electricity sector. Balancing supply and demand is a prerequisite to meet this objective. This section firstly looks at the role of balancing supply and demand of the sector and how supply and demand is conventionally balanced.

Looking ahead, balancing supply and demand is challenged by the development of low carbon generation following the UK's legally binding target for decarbonisation (Strbac *et al.*, 2016a). Therefore, secondly, this section considers inflexibility and intermittency – characteristics of low carbon generation. In order to deal with such inflexibility and intermittency, new sources of energy flexibility are needed. This section ends with a closer look at energy flexibility.

2.2.1.1 The role of balancing supply and demand

Since the beginning of the World War I, many factories in Britain were rapidly built and electricity became the "*national choice*" to power them (Everett *et al.*, 2012). Therefore, one of the key concerns for GB's electricity sector was to produce sufficient electricity to meet total demand. Electricity was mainly generated from small and inefficient coal fired power stations (Everett *et al.*, 2012). Because coal was cheap, abundant and indigenous to Britain, there was enough electricity to meet total demand (Helm, 2004).

However, GB's electricity sector needs to ensure that electricity supply balances with demand at all times, otherwise the system fails (Boyle, 2007). Historically, systems did collapse and caused blackouts over a wide area for many hours. On Christmas Day 1960, for example, widespread grid failures were described as "*politically embarrassing*" (Everett *et al.*, 2012). Recently, on 9 August 2019, the blackout across different regions in the UK including London caused "*a lot of disruption to a lot of people*" (National Grid, 2020). These blackouts were caused by a failure to supply sufficient electricity to meet peak demand. Therefore, this section focuses firstly on describing how the sector balances supply and demand, conventionally by ensuring supply meets demand at all times.

Meeting demand at all times is not easy to achieve. In practice, the demand (or load, technically) for electricity varies widely according to the season and the time of day. Figure 2.1 shows the differences between the electricity demands of winter and summer on a typical week day (NIC, 2016). It can be seen that the electricity demand at night in summer was 35GW, while a peak in demand at night in winter could go up to 55GW. 35GW could thus be used as a "*base load*" (Everett *et al.*, 2012). Electricity generation for variable demand would be added 'on top' of this "*based load*".

Demand may also change hourly because of changes in human activities, such as when computers are turned on in the morning at work, when there is a popular TV show or a football match or when people cook their evening meals. Moreover, demand at peak time (usually from 4pm to 7pm) may also increase due to the development of Electric Vehicles (EVs). According to the National Infrastructure Commission (2018), energy demand from increasing population and the uptake of

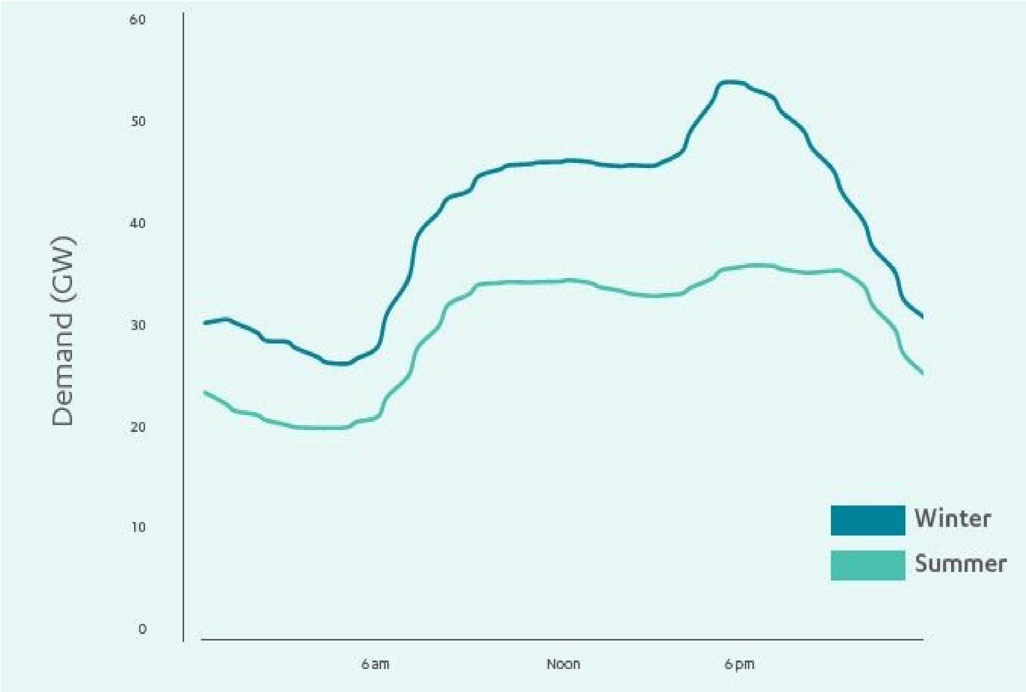


Figure 2.1: Winter and summer electricity demand in GB on a typical week day (NIC, 2016)

electric vehicles may rise from 9-26% by 2030. This increase in demand may impact the task of balancing supply and demand of the network.

Since demand for electricity is not constant in the short term, GB's electricity sector has needed to ensure that sufficient spare generation capacity was available, over and above that needed to meet the maximum peak load demand. The sector also needed to ensure that spare capacity was available in case of unexpected events such as a breakdown of a power plant (Boyle, 2007). Such spare capacity is often called margin capacity. The Winter Outlook published by National Grid (National Grid, 2019d) forecasted that the margin capacity was 12.9% in the 2019/2020 winter.

National Grid is the organisation in charge of balancing supply and demand, i.e. managing the system. This is achieved through the use of different power plants which can be started up quickly (i.e. quick start-up power plants). These power plants include:

- A small "*open cycle*" gas-turbine: It can be run up to full power in minutes. However, it provides a low capacity and a low efficiency (Everett *et al.*, 2012).
- A pumped-storage hydro power plant: It can get to full power very quickly by diverting water flow onto turbines such as Dinorwig.
- A large combined cycle gas turbine operating at part-load: It may need 8 hours to reach full power but it can operate and provide outputs within an hour. This type of power

source can also be run at part-load (producing half of the full capacity), but there is a trade-off for this flexibility from lower efficiency and higher carbon emissions (Boyle, 2012).

These power plants that ensure margin capacity provide energy flexibility for the system. Here, the electricity system always needs to maintain a level of flexibility. Energy flexibility of a system, conventionally, refers to the ability to "*respond rapidly to large fluctuations in demand and supply, both scheduled and unforeseen variations and events, ramping down production when demand decreases, and upwards when it increases"* (IEA, 2008). In accordance with this definition, energy flexibility is essential for the supply of the system to meet with changes in demand. In this context, energy flexibility in the electricity sector is achieved by the characteristics of the generation mix in the system, e.g. quick start-up power plants.

However, with the UK legally binding target of Net Zero emissions by 2050 (BEIS, 2019b), the generation mix is likely to change and favours low carbon generation including nuclear power, solar and wind power. Such changes in the generation mix, together with the increased demand from the uptake of electric vehicles and increasing population (mentioned above) may reduce the ability of the system to balance supply and demand or the flexibility of the system using the above quick start-up power plants to meet changes in demand conventionally. This potentially becomes a major policy and operational challenge for the sector. The following section describes the main characteristics of low carbon generation and shows that low carbon generation is unable to provide the needed capacity margin as quick start-up power plants.

2.2.1.2 Inflexibility and intermittency – characteristics of low carbon generation

Nuclear power and renewables can be classified as low carbon generation, which means that they produce zero or lower carbon emissions than extant, conventional power plants. Nuclear power plants need 24-36 hours to reach full efficient capacity from start-up and are harder to turn off compared to coal and gas power plants (Everett *et al.*, 2012). Nuclear power plants therefore have very limited flexibility (i.e. are inflexible) and are mainly used to supply the base load (Boyle, 2012).

Renewable energy is the "*energy obtained from the continuous or repetitive currents of energy recurring in the natural environment*" (Twidell and Weir, 1986). In the UK, renewables are generated from mainly wind power (onshore and offshore wind) and solar photovoltaic. Wind and solar power are intermittent because they can make "*time-variable*" contributions to "*time-variable*" demand (Boyle, 2012). The output of wind power depends on the random nature of wind. When the wind is calm, electricity cannot be produced. When the wind blows to a certain speed (the 'cut-in' wind speed), the turbines operate to generate electricity. When the wind blows more than a certain speed (the 'shut-down' wind speed), the turbines stop to avoid damage. Even at modest wind speeds, outputs from wind turbines vary considerably from minute to minute (Everett *et al.*, 2012). The variability of wind power can also be calculated by a capacity factor. If the turbines operate at full rate throughout the year, the capacity factor is 100%. However, typically, wind power only has a capacity factor of 25% (Everett *et al.*, 2012).

In Britain, solar energy is in the form of solar PV installed on the roof of a building, a house or on agricultural land. Solar PV is intermittent because output can reduce if there are passing clouds. Additionally, PVs only produce electricity during the day-time and the output is higher in summer than in winter. In contrast, demand in winter is certainly higher than in summer (Boyle, 2012). Hence, there is often a mismatch between supply and demand, which could be overcome partly by combining solar PV with energy storage, such as batteries.

With the intermittency of renewables and inflexibility of nuclear power, the change in generation mix towards low carbon generation challenges the electricity system's ability to maintain sufficient flexibility to meet demand at all times (Strbac *et al.*, 2016a). However, such challenges are expected to be resolved with new sources of energy flexibility as explored in the next section.

2.2.1.3 Energy flexibility

If low carbon sources continue to make an increased contribution to electricity generation, according to Boyle (2012), the question needs to be considered is *to what extent will these existing energy systems need to be modified and supplemented?* This section (1) defines energy flexibility and (2) describes new sources of energy flexibility and (3) explores the attractiveness of these new sources.

2.2.1.3.1 Definition of energy flexibility

Conventionally, as identified in section 2.2.1.1, energy flexibility of the system refers to its ability to turn on 'quick start-up' power plants in response to increases in demand. EURELECTRIC (2014) look beyond this definition of energy flexibility and state: "*On an individual level flexibility is the modification of generation injection and/or consumption patterns in reaction to an external signal (price signal or activation) in order to provide a service within the energy system".* This definition deviates from conventional energy flexibility in which supply changes to meet increases or decreases in demand. Rather, demand can also change to match supply in order to provide the necessary supply and demand balancing, and consequently, ensure electricity security of supply.

Department of Business, Energy and Industrial Strategy (BEIS) in "Upgrading our Energy System – smart systems and flexibility plan" (BEIS and Ofgem, 2017) favours a more market-oriented approach for the definition of flexibility. This plan is based on two broad types of flexibility which are (1) price flexibility (occurring when any party varies its demand or generation in response to the price of energy, and network use at a particular time and/or location); and (2) contracted flexibility (where parties trade and directly contract with one another to *procure* flexibility). This approach is relevant to new sources of energy flexibility explored in the following section.

2.2.1.3.2 New sources of energy flexibility

Writing over a decade ago, Boyle et al (2007) considered the impact of renewables on the electricity grid in the future, especially the impact of intermittency, and suggested some possible solutions such as energy storage and demand-side management, to maintain energy flexibility on the system. In the current system of fossil fuels, flexibility can be taken from gas power plants which can be quickly started up (IEA, 2008; Bertsch *et al.*, 2012). If the system moves towards low carbon generation, which are inflexible and intermittent, some new sources of flexibility will need to be deployed, including:

- Demand side flexibility, to change patterns of demand
- Storage, to store energy and use when needed, it means to increase demand when there is insufficient demand on the system or meet demand when there is insufficient supply available.
- Interconnection, to import electricity at times of peak demand and sell export electricity at time of surplus supply from/to other parts of the world via transmission grid (NIC, 2016).

These new sources of flexibility are looked at in more detail to understand their role in GB's current electricity system.

Demand side flexibility:

Demand side flexibility can potentially help consumers save money by switching their demand to times of low demand relative to the available supply. This value has been realised by industrial and commercial consumers to an extent. Domestic consumers can also reduce their bills, for example, by avoiding turning on the washing machine at the time when people cook their evening meals, instead turning it on at night when people are asleep. Recently, demand side flexibility is underused in the UK because of the failure in communicating its benefits (for both consumers and electricity network) to consumers (NIC, 2016). However, with the planned roll out of smart meters, this could change in the future. More and more consumers will receive transparent information about their usage and tariffs, which could prompt them to change their demand patterns (BEIS, 2020b).

Storage:

Historically, it has been difficult and expensive to store electricity (Everett *et al.*, 2012). Currently, there are many storage innovations driven by the use of mobile phones and electric vehicles (NIC, 2016). Regarding electric vehicles (EV), the global number has increased 40% annually (IEA, 2020). In line with this trend, the government has improved the EV charging infrastructure and announced an end to the sale of all new conventional cars and vans using petrol or diesel by 2040 to support the uptake of EVs in 2017 (BEIS, 2017). Recently, the government brings this forward from 2040 to 2030 (DfT and BEIS, 2020).

Storage technologies are increasingly attracting investment as the cost of, for example, lithium ion batteries has reduced from $3000/kWh in 1990 (NIC, 2016) to $176/kWh in 2018 (Goldie-Scot, 2019). This drop in price makes the economics of combining solar energy and battery more attractive than solar energy alone. This may fundamentally disrupt the energy system as it provides an opportunity for consumers to actively engage in electricity generation and consumption. The UK Government has also announced investment of £246 million in battery technology (BEIS, 2017), which increases the value of not only storage technology but also new sources of flexibility in general.

Interconnection:

Historically, Britain has had a low level of interconnection because subsea cables need to be built to allow the electricity to be imported and exported between continental countries. Today, there are five interconnectors – one to Republic of Ireland, one to Northern Ireland, one to France, one to the Netherlands, and one to Belgium which constitute 5GW of interconnection capacity (Ofgem, 2020b). It is expected that new connections will be built to Norway, Ireland, France and Denmark in the coming years (expected delivery date 2020-2022) (NIC, 2016). However, this source may be less attractive to investors because of uncertainty associated with Brexit.

2.2.1.3.3 The attractiveness of new sources of energy flexibility

These new sources are expected to help the sector to not only decarbonise but also balance supply and demand at all times. In coping with decarbonisation, the sector needs to integrate low carbon generation which means that the system will be significantly affected by intermittent sources of renewables. National Grid (2017) has suggested that the total amount of renewable generating capacity could increase to 60% of installed capacity by 2050, nearly doubling the capacity in 2016.

A research project from Imperial College London (Strbac *et al.*, 2015) shows that deploying renewables with new sources of flexibility is the most cost effective way to a low carbon future, with a potential to save consumers £2.9 billion to £8.1 billion per year by 2030 (NIC, 2016). The government and Ofgem are also collaborating to support the sector in a move towards a flexible electricity system by investing £246 million in battery technologies as mentioned in section 2.2.1.3.2 (Ambrose, 2017; BEIS and Ofgem, 2016; 2017). The new sources of flexibility detailed above may therefore be the energy flexibility choice for a low carbon future. The attractiveness of new sources of energy flexibility is further discussed in section 2.2.2.4.2.

In summary, this section identified the main objective of GB's electricity sector which is balancing supply and demand at all times. GB's electricity sector already has a level of energy flexibility. This flexibility is maintained by the 'quick start-up' characteristics of extant gas power plants. However, in the context of decarbonisation with the integration of inflexible and intermittent low carbon generation, GB's electricity sector is facing challenges to maintain such level of energy flexibility. New sources of energy flexibility such as demand side flexibility, storage or interconnection might be obtained to help the sector compensate for the inflexibility and intermittency of low carbon generation while coping with decarbonisation. The following section moves from describing the properties of the system to looking at the development of the grid and the sector. Some key landmarks of GB's electricity sector are set out.

2.2.2 Historical and current context

During the post-World War I period, most power stations were operating inefficiently with the efficiency of only 10% in 1920 (Everett *et al.*, 2012). The UK government reviewed the national problem of electricity supply and created the Central Electricity Board (CEB) which was charged with connecting up fragmented privately owned generation plants to form the basis of a networked supply. A decision to build a transmission network, the National Grid, was confirmed in 1926 to fulfil this task (Everett *et al.*, 2012). This section reviews five key landmarks (1) 1930s – the Grid, (2) 1947 – Nationalisation, (3) 1990s – Privatisation, (4) 2000s – Environmental concern and (5) The changes – Decarbonisation, decentralisation, democratisation and digitisation. These key landmarks reveal the important role of energy policy and three key objectives of GB's electricity sector (1) to ensure electricity security of supply, (2) to reduce carbon and (3) at lowest costs.

2.2.2.1 1930s – The Grid

In 1934, the first National Grid was completed and has since been expanded and upgraded to cope with increases in demand (Everett *et al.*, 2012). During the 1930s, the system was owned by the government while the stations and distribution companies were privately owned (Everett *et al.*, 2012). Initially, electricity generation within regions of the UK could be linked to transmit and distribute electricity to end consumers, allowing the sector to use electricity from different places to cover peak demand (Boyle, 2012). In 1938, the network was developed to connect all regions within the UK, which made the task of meeting peak demand easier (Everett *et al.*, 2012). However, electricity in particular and energy in general became so important after World War II that the UK Government sought to control the production and distribution of energy (Helm, 2004), which led to nationalisation in 1947.

2.2.2.2 1947 - Nationalisation

Nationalisation in 1947 paved the way for larger power plants to be developed and operated at higher efficiencies, under the state owned monopoly – the Central Electricity Generating Board (CEGB) (Everett *et al.*, 2012). CEGB sold electricity to state owned Area Boards, each of which has a monopoly relationship with its customers (ibid). Investment decisions in the nationalisation period were not made as in a normal competitive market but agreed by the government and industry managers. Bills were then paid by consumers and taxpayers. Investments in larger units were favoured over smaller ones (Helm, 2004). Coal was burned in large power stations and *far* from end consumers.

From nationalisation in 1947 to privatisation in the 1990s, the share of primary electricity sources varied. Coal was dominant in electricity generation and accounted for 98% of the UK's electricity in 1950 (Everett *et al.*, 2012). After 1950, coal usage was challenged by oil as the decline in oil price made burning oil to generate electricity cheaper than burning coal. However, increases in the oil price during the 1970s reduced the use of oil as a major generation source (ibid). During the 1950s the first nuclear plants were opened and supplied electricity to the grid (ibid). In the 1970s, the Government assumed that the oil price would continually grow and threaten energy security, so they backed coal and supported nuclear power. Such support was given in light of sunk investment in large scale power stations built in the nationalisation period. Another rationale behind this support was energy self-sufficiency. Coal and nuclear power were produced in Britain, helping the country move away from the energy imports (Helm, 2004). At a similar time, natural gas discovered in the North Sea, started to generate small amounts of electricity using simple gas turbines (Everett *et al.*, 2012).

The CEGB used 'merit order' to control the operation of power plants. Nuclear power stations and the largest and most efficient coal power plants having the lowest running cost supplied the base load. Then, coal power plants with lower efficiency were the next in the merit order, but usually did not run in summer when demands were low. Simple gas turbines were then operated only to meet peak demand in winter (Everett *et al.*, 2012).

During the 1950s, 1960s and 1970s, the nationalised status of the electricity sector was unchallenged by Conservative governments because the key objective was to build as many power stations as possible to cope with increases in demand (Helm, 2004). The government believed that energy demand would increase because energy was increasingly important, not only for manufacturing goods, but also for transporting goods and in service sectors (Helm, 2004).

At the beginning of the 1980s, the focus of the government moved to security of supply. The government imposed higher gas prices, built more nuclear power stations and sustained the coal industry. An added political dimension was the coal miners' strikes in 1981 affecting security of supply. However, at this stage, there was no recognition that the threat of miners' strikes on energy security could be solved by privatising the electricity sector (Helm, 2004).

In the context of the world economic recession in the 1980s, the British economy became unstable, with the rise of unemployment and the drop in the value of sterling, which caused the public sector to face tight budget constraints (Helm, 2004). This influenced the electricity sector: electricity prices had to increase in order to create revenue for the government and investments were curtailed due to lack of funds. However, the recession led to an excess in supply of electricity as a result of the power station construction programme through the 1950s to 1970s and a fall in demand through reduced economic activity. The operation of the electricity sector thus became inefficient. Electricity price, therefore, reduced although the government wanted to push prices up, which threatened the nationalised status of the industry and ultimately paved the way for private sector led initiatives, mainly to finance investment (Helm, 2004). Nigel Lawson, who became Secretary of State for Energy in 1981, argued that energy should be treated as a market commodity and the job of balancing demand and supply should be left to the market, changing the history of the sector by turning to a new page: privatisation.

2.2.2.3 1990s – Privatisation

In the 1990s, the UK energy sector was privatised (Helm, 2004). Privatisation opened up an opportunity for competition, for gas and green niches (such as wind and solar power) to enter the electricity market. At the beginning of the 1990s, the share of GB's electricity generation included 75% coal, 20% nuclear and 5% other (e.g. oil) (Helm, 2004). By 1992, when the technology of combined cycle gas turbines (CCGT) was well developed, gas rapidly displaced coal for several reasons (Everett *et al.*, 2012). First, CCGT was cheaper and quicker to build than coal and nuclear stations. Second, Area Boards became Regional Electricity Companies (RECs) which were allowed to build their own power stations. Initially, they were monopoly suppliers to a number of loyal customers and were able to sign a fixed-price contract for 15 years' future supply of gas. Therefore, investment in CCGT was relatively risk-free which turned on the so called "Dash for Gas" period.

Third, the battle between the Conservatives and the miners (mentioned in section 2.2.2.2), representative by NUM (National Union of Mineworkers), gave rise to the government's approval for natural gas to be used in power plants. Last but not least, burning gas produced less CO_2 than burning coal (Everett *et al.*, 2012).

Under privatisation, the system is operated quite similar as now. Most power stations are privately owned and required to compete with each other. The system operates under a competitive wholesale market, regulated by Ofgem (Office of gas and electricity market). Ofgem, through trading arrangements, administers how the electricity is traded, who gets paid, who is given licenses to generate, sell or distribute electricity. The old trading arrangement, known as the Pooling and Settlement Agreement (PSA) allowed market participants to offer non-binding bids into the whole sale market (Office of Electricity Regulation, 1998). PSA also allowed bilateral trading between generators (ibid). The New Electricity Trading Arrangements (NETA) was introduced into the electricity sector in 2001, legally binding market participants to their bids (Ofgem, 2002). NETA was operated in England and Wales, then extended to Scotland under the name British Electricity Trading and Transmission Arrangements (BETTA) in 2005 (Ofgem and DTI, 2005). Now, under BETTA, there is one whole-sale electricity market for Great Britain and one system operator (National Grid) (Elexon, [no date]).

The day-to-day running of the wholesale market is carried out by the National Grid Company who owns the grid (Everett *et al.*, 2012). In Apr 2019, National Grid was separated into National Grid Electricity Transmission (who owns the grid) and the Electricity System Operator (ESO) (National Grid, 2019c). At any given time, the ESO uses its computer model to estimate the next few hours demand and invites bids for electricity supply. Power station owners respond using their computer systems. The lowest bids are then taken first to supply electricity. Renewables such as wind power with the lowest running costs are selected first to supply the base load, then come the nuclear power plants with low fuel costs. After that, coal and gas power plants are chosen. Lastly, due to their high flexibility, hydro power plants (although with zero fuel costs) are drawn in (Boyle, 2012).

The ESO ensures electricity supply and demand is balanced second by second. The ESO does this using its Balancing Mechanism. Market participants (traditionally they are mainly generators) can bid into this Balancing Mechanism market at very short notice. If market participants fail to fulfil their bids, they need to pay an imbalance price (Ofgem, 2013). This imbalance price is calculated by Elexon who administrates the Balancing and Settlement Codes defining the rules for the Balancing Mechanism market (Elexon, [no date]).

The 1990s was also the decade in which the impact of using fossil fuels as energy sources on climate change was recognised in policy making circles (Helm, 2004). The Non-Fossil Fuels Obligation

(NFFO) was introduced in 1990. This obligation required electricity suppliers to buy a certain amount of nuclear power from the wholesale market (Geels *et al.*, 2016). In 1997, the Kyoto protocol (UNFCCC, 1997) on Climate Change was signed by 37 industrialised countries, among which the UK set its target to reduce carbon emissions by 12.5% below the 1990 levels by 2012 (DECC, 2015c). This commitment has fundamentally influenced GB's electricity industry and energy policy in particular (Geels *et al.*, 2016). In the next section, climate change and the development of policies to address it are discussed.

2.2.2.4 2000s – present

2.2.2.4.1 Environmental concern

Environmental concerns have forced the government to participate in actions to mitigate climate change. In 1990, when gas was dominant, gas helped the UK to reach UK's national early climate change commitments (Helm, 2004). Turning to the first half of the 21st century, there was a concern that carbon emissions would increase if the UK government does not change its energy policy (Helm, 2004). Renewables were then included in NFFO (Geels *et al.*, 2016). NFFO was replaced by Renewables Obligation in 2002, which supported large-scale renewables. In 2000s, climate change received far more attention from the public. The 2003 White Paper *Our Energy Future* (DTI, 2003) with an aim of creating a low-carbon economy advocated renewables, whereas the 2007 White Paper *Meeting the Energy Challenge* (DTI, 2007) focused on renewables, nuclear and coal with carbon capture and storage (CCS). However, the renewable policies had several flaws including lack of incentives, long-term commitments and innovations, although electricity generated from renewables increased from 3% in 2002 to 5.8% in 2008 (Geels *et al.*, 2016).

Perhaps the most radical change in energy policy by the UK Government was in response to the Climate Change Act 2008, in which the UK legally committed to reduce 80% carbon emission by 2050, from 1990 levels (Geels *et al.*, 2016). This created momentum for the government to deliver requisite policies to support low carbon transitions (Geels *et al.*, 2016). These policies included UK Low Carbon Transition Plan in 2009, an amended version of the Renewables Obligation in 2009, the UK Renewable Energy Strategy in 2009, the Carbon Plan in 2011, the Energy Bill in 2012 and so on (Geels *et al.*, 2016). The most recent incentive of the government is the Electricity Market Reform (2013) with the Feed-in-tariff Contract for Difference. It is a long-term contract between an electricity generator and a contract counterparty which enables electricity generators to receive a fixed price for their electricity generation capacity over the duration of the contract (DECC, 2011). This incentive gives greater certainty and stability of revenues to electricity generators by reducing their exposure to volatile wholesale prices (DECC, 2015b).

The most recent global commitment of the UK Government to carbon reduction was the Paris Agreement 2015, which was signed by the European Union on behalf of the UK and other EU countries. These countries committed to reduce the rise of global temperature to well below 2^{o}C (CCC, 2015b). The UK government was looking to legitimate this commitment in the UK legislation (The UK Parliament, 2016). In 2018, the Intergovernmental Panel on Climate Change (2018) published a report to call for urgent action of countries in the globe to tackle climate change as global average temperature has already risen 1^{o}C compared to pre-industrial level. Following this, the Committee on Climate Change (2019) provided the UK government with some practical recommendations to keep on track with Net Zero in May 2019. One month after this, the government passed the legislation to bind the UK to NetZero emissions by 2050 (BEIS, 2019b).

2.2.2.4.2 Meeting decarbonisation targets

Meeting decarbonisation targets goes alongside ensuring electricity security of supply. In coping with both decarbonisation and matching supply to demand, one possible option is to take the base load from existing fossil fuel plants and then add carbon capture and storage (CCS) to these fossil fuel plants. Another possible option is to further integrate low carbon generation to the power system and use new sources of flexibility to compensate their inflexibility and intermittency as identified in section 2.2.1.3.2.

With CCS, most of the carbon emissions emitted from fossil fuel plants is separated and sequestered underground (Boyle, 2012). With the decarbonisation target set in 2008 when 91.5% of electricity demand was met by fossil fuels, CCS had a potential to support GB in meeting this target (Smith, 2011). CCS can capture about 90% of the carbon emissions, but it causes the efficiency of the power plants to reduce by 20-25% by requiring more fossil fuel to produce the same amount of electricity (Boyle, 2012; Everett *et al.*, 2012; Smith, 2011). It is also likely to increase the cost of supply associated with infrastructure to transport the carbon emissions through pipelines to storage locations (Smith, 2011). Moreover, going with CCS means that the future of GB's security of supply would be less secure due to the global political and economic uncertainties of fossil fuel supply, particularly coal which is imported mainly from Russia, South Africa, and Columbia (Smith, 2011). From 2005 to 2010, the government allocated £45 million to innovation in CCS technologies. Subsequently, it committed £1 billion to develop CCS technologies but stopped investment in 2015 (Gosden, 2015).

In the National Infrastructure Assessment (2018), the National Infrastructure Commission concluded that CCS is rarely the most cost effective option for reducing carbon emission in the power sector whereas energy flexibility may reduce total energy system costs by between £1 - £7 billion per year. Moreover, Great Britain has aged power stations. About two thirds of them will retire by 2030 (NIC, 2016). Given these retirements, the CCS option cannot take advantage of existing infrastructure and spread investment costs over multiple units, which means new sources of flexibility route become more attractive.

In the context of meeting the UK Government's Net Zero emissions target instead of 80% decarbonisation, the CCS option has recently been brought back in with a new term - CCUS (Carbon capture, usage and storage). New CCUS technology can potentially capture 100% of carbon emissions with a cost similar to that of CCGT (BEIS, 2017). In the Clean Growth Strategy (2017), BEIS confirmed an investment of up to £100 million is needed for innovations in CCUS and an associated demonstration programme. CCUS is deployed to reduce carbon emissions from heavy industry (Energy Transitions Commission, 2018) rather than being used in the electricity sector. This curtailment of investment would suggest the government no longer supports the option of CCS for electricity generation.

With the objectives of ensuring electricity security of supply and meeting decarbonisation targets at lowest cost to GB's electricity sector, the following section investigates further developments in the sector. Many of these can be accounted for by the so-called 4Ds – Decarbonisation, Decentralisation, Democratisation and Digitisation.

2.2.2.5 Sector developments - Decarbonisation, Decentralisation, Democratisation and Digitisation (the 4Ds)

The previous sections have introduced the historical background of GB's electricity sector and indicated how system energy flexibility are embedded in the development of the sector with the objectives of ensuring electricity security of supply and meeting decarbonisation at lowest costs. This development would potentially affect future changes the electricity sector; therefore, this section examines the current changes of the sector with decarbonisation, decentralisation democratisation, and digitisation (the 4Ds). These 4Ds are interrelated and it is unclear which one is the main driver; hence, the order of the 4Ds set out below do no imply any order of importance or priority.

2.2.2.5.1 Decarbonisation

The UK has officially entered a decarbonisation period after committing to reducing carbon emissions by 80% by 2050 from the 1990s level in the Climate Change Act 2008. In 2019, the UK Government committed to Net Zero carbon emissions by 2050, following recommendations from the Committee and Climate Change as mentioned in section 2.2.2.4.1. The most attractive option to meet the decarbonisation target while ensuring system flexibility is to use new sources of flexibility as identified in section 2.2.1.3.2 and 2.2.1.3.3. Currently, the UK government is in the process of developing another set of Greening Government Commitment targets covering the period of 2020-2025 which was stated in the closing letter from the Minster of State for Business, Energy and Clean Growth for the Net Zero government inquiry (BEIS, 2019a).

Meeting Net Zero is "*necessary, feasible and cost-effective*" (CCC, 2019, p.8). The cost for achieving Net Zero is estimated to be less than 1% of the GDP while helping the UK achieve its national and international (Paris Agreement 2015) targets. Net Zero carbon emissions can also bring benefits to wider society including increases in human health. It is argued that "*benefits could partially or fully offset costs*" of tackling climate change (CCC, 2019, p.213).

The Committee on Climate Change looked at the progress of decarbonisation in the COVID-19 outbreak and reported this to Parliament in June (2020). In this progress report, 54% of carbon emissions reduction in 2019 is from the power sector. These reductions are expected to accelerate because the price of off-shore wind was recorded at a lower price than before and lower than gas power plants (Evans, 2019). The benefits of new sources of energy flexibility are also expected to contribute to the Net Zero target. It is suggested that The Energy White Paper due later in 2020 should set out how the sector can realise the economic benefits of energy flexibility (CCC, 2020). The following section continues reviewing the remaining Ds – Decentralisation, Democratisation and Digitisation and associated changes in the sector.

2.2.2.5.2 Decentralisation

Decentralisation is defined in terms of location and connection. Decentralised energy/ distributed energy is generation and distribution of energy which is located near to, or directly connected to, a point of consumption including buildings or communities (Woodman and Baker, 2008; Watson and Devine-Wright, 2011), or to the distribution network (IEA, 2002). In most cases, location and connection approaches are similar because almost all generation from consumers' location is connected to the distribution grid (Pepermans *et al.*, 2005).

The current electricity system is locked-in to centralisation (Rydin *et al.*, 2012). Decentralisation emerged as a possible solution to reduce carbon emissions, while the current centralised system is of concern, given security of supply (ageing infrastructure, generation failure) and fuel poverty (Rydin *et al.*, 2012). Decentralised or distributed energy includes smaller scale local generation such as solar panels and wind power (Ofgem, 2007). Here, decentralisation increase the share of intermittent renewables in the generation mix (Chmutina and Goodier, 2014) and push the sector towards the new sources of energy flexibility option.

Considering decentralised energy as resources connected to the distribution network (IEA, 2002), electric vehicles become a decentralised resource. The take-up of electric vehicles may increase the energy flow via distribution grids at one time (e.g. when the owner charges their vehicles), which then may lead to distribution grid constraints and consequently, threaten the security of electricity supply.

In terms of governance, decentralisation is considered as the process of transferring the decision making from an upper hierarchy level to a lower one, from central government to subnational units of the government (World Bank, 1998; Alanne and Saari, 2006). With this consideration, decentralisation provides opportunities for democratisation.

2.2.2.5.3 Democratisation

Natural and human-caused disasters cause disruptions in the operation of the energy systems which consequently drive the transformation of the energy sector (Tomain, 2015). Such transformation is likely to involve more consumers participation and democratisation (ibid). Morris and Jungjohann (2016) explore transitions of Germany to Renewables (Germany's Energiewende) to argue that with democratisation of energy, the future would be cleaner, more competitive and more democratic.

Democratisation is the process of building democracy (Modelski and Perry, 1991). In terms of energy, democratisation has been approached from different perspectives. Trade Unions define energy democratisation as a process of moving from fossil fuel to renewables, moving from privatisation to public ownership to strengthen the power of workers and trade union (Sweeney, 2013; Weinrub, 2014). Those with a citizen perspective think of democratisation as a means to support moving from fossil fuel to renewables and moving the power from a few large energy companies to prosumers - consumers that both consume and produce energy (The European Federation of Renewable Energy Cooperatives - REScoop, 2015; Morris and Jungjohann, 2016). The central goal of democracy is to give a greater voice to people by promoting participation in political and economic institutions (Tomain, 2015). Thus, democratisation can be thought of as the decentralisation of decision making.

Regardless of these different definitions and approaches to democratisation, they reflect a move of GB's electricity sector towards renewable generation and empowering consumers by providing them with an opportunity to participate in decision making within the sector. The following section looks at digitisation which closely relates to decentralisation and democratisation.

2.2.2.5.4 Digitisation

The International Energy Agency (2017) defines digitisation as the increasing use of information and communication technology. Digitisation not only supports more interaction between consumption and production (Midttun and Piccini, 2017) but also actively helps the system to manage energy flows on electricity networks using technologies such as smart meters (Wolfe, 2008). Funcke and Bauknecht (2016) also support this argument by stating that using information and communication technology (ICT) to manage electricity loads is an option to increase energy flexibility at distribution grid. As such, digitisation enables effective management of an increasingly complex system and, it is claimed, facilitates democratisation and decentralisation.

In summary, section 2.2.2 reviewed the historical and current context of GB's electricity sector in which transitions to low carbon futures are proceeding. The sector is attempting to meet Net Zero target set out in 2019 while concerning about energy security and affordability. Within this context, four changes can be observed and associated with the 4Ds – Decarbonisation, Decentralisation, Democratisation and Digitisation. Changes in sources of energy flexibility to new ones including demand side flexibility, storage and interconnection (identified in section 2.2.1.3.2) are supported by the 4Ds and potentially become the most attractive option for low carbon futures. The following section looks at existing research in the changes of GB's electricity sector which is conceptualised as "transitions".

2.3 TRANSITIONS TO LOW CARBON FUTURES OF GB'S ELECTRICITY SECTOR

The change of the electricity sector in response to climate change has been conceptualised as a "*transition to a low carbon future*" by the Stern review (2007). Since this publication, research has been undertaken to explore transitions to low carbon futures for the sector which can be conceptualised as socio-technical transitions to sustainability. This conceptualisation and some main characteristics of sustainability transitions are firstly considered. As this transition is future-oriented, futures play an important role in transitions research and are reviewed, including a whole system analysis. Finally, energy flexibility in transitions to low carbon futures are also reviewed. The section ends with a number of research gaps in knowledge.

2.3.1 Socio-technical transitions to sustainability

This section considers the literature on socio-technical transitions to understand how transitions to a low carbon future of GB's electricity sector can be conceptualised as socio-technical transitions to sustainability. After that, some main characteristics of sustainability transitions which are relevant to the GB's electricity sector are identified.

2.3.1.1 Transitions of GB's electricity sector

The transition literature initially focused on technological transitions (TT). Geels (2002) defined TT as "*major technological transformations in the way societal functions are fulfilled*". Technology, however, can only fulfil functions in association with human agency (Geels, 2002). Thus, TT not only consist of changes in technology but also in other elements such as user practices, regulations, industrial networks, infrastructures and culture. Socio-technical systems, in a functional sense, are the linkages between elements necessary to fulfil societal functions (Geels, 2004).

The electricity sector has been conceptualised as a socio-technical system (Geels, 2002) as it forms links between elements of the sector necessary to supply electricity. These elements include actors (individuals, firms, organisations) and institutions (societal and technical norms, regulations, standards of good practice) and material artefacts and knowledge (Geels, 2004). These elements of a socio-technical system are tightly inter-related and dependent on each other (Markard et al., 2012). The GB's electricity system includes electricity generation, electricity network and electricity consumption (McMeekin et al., 2019). These sub-systems are distinctive regarding technologies, actors and institutions (ibid). One representation of the system is presented in the systems map (Figure 2.2).

As illustrated in Figure 2.2, beside a combination of technologies, GB's electricity sector also accommodates a wide range of actors including the government (includes governmental organisations), Ofgem – the regulator, power generator, National Grid – system operator,

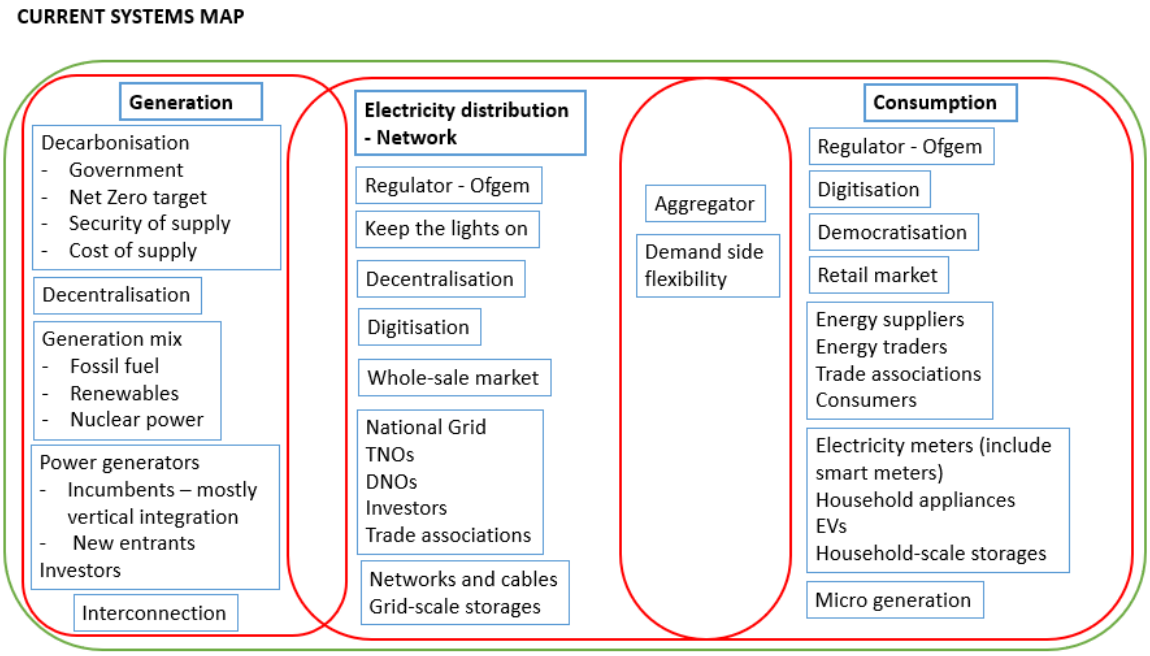


Figure 2.2: Current systems map of GB's electricity sector – adapted from McMeekin et al (2019)

Transmission network operators (TNOs), Distribution network operator (DNOs), investors, energy traders, energy suppliers (both incumbents and new entrants), trade association, aggregators for demand side flexibility, consumers and so on.

Many researchers argue that solving climate change requires a transition to more sustainable socio-technical systems (Raven and Verbong, 2009; Lachman, 2013). Hence, a transition to a low carbon future to mitigate climate change of GB's electricity sector is classified as the transition to sustainability, which is defined as long-term, multi-dimensional, and a fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption (Markard *et al.*, 2012). The following section looks at some main characteristics of sustainability transitions in the literature.

2.3.1.2 Main characteristics of sustainability transitions

This section investigates three main characteristics of sustainability transitions in literature (Köhler *et al.*, 2019) which are relevant to GB's electricity sector.

2.3.1.2.1 Multi-dimensional and multi-actor processes

Transitions to sustainability are non-linear, underpinning by contested processes with multi-dimensions and multi-actors (Köhler *et al.*, 2019; Geels, 2020). As mentioned above, a socio-technical system consists of many elements, including not only technologies but also user practices, regulation, networks, infrastructure, markets and so on (Geels, 2004). These elements are linked together and also aligned with existing technology, which creates difficulties for radical technological breakthrough (Geels, 2002).

In socio-technical systems, the role of human actors is emphasised. Socio-technical systems "*do not function autonomously, but are the outcome of the activities of human actors*" (Geels, 2004, p.900). Activities of actors can (re)produce the elements and linkages in the socio-technical systems (Geels, 2004; 2005c). Human actors are embedded in social groups, which include firms, industries, users, societal groups, public authorities, research institutes. They share some characteristics such as similar roles, responsibilities, norms and perceptions (Geels, 2004). However, human actors and social groups are not free to act. Their activities are shaped, guided and modulated by rules which coordinate and structure activities. There are three kinds of rules (1) regulative rules referring to formal rules such as government regulations; (2) normative rules referring to social obligation such as values, norms, role expectations, duties, rights, responsibilities; and (3) cognitive rules referring to social groups' cultural rules which are taken for granted such as beliefs and jargon. Actors carry and reproduce the rules in their activities (Geels, 2004).

2.3.1.2.2 *Stability and change*

Stability and change are core issues in sustainability transitions research (Köhler *et al.*, 2019). For example, GB's electricity sector changes due to the development of many green innovations such as PVs, wind energy, electric vehicles, heat pumps and so on while it experiences stable path-dependencies related to fossil fuel power plants, petrol car use and so on (Unruh, 2000). Transitions in the electricity sector does not come easily because of incumbents working with government to maintain institutional status quo (McMeekin *et al.*, 2019). The stability here comes from the alliances of incumbents and policy makers (i.e. interactions of actors) (Geels *et al.*, 2014). Literature on stability and change is further reviewed in section 2.4.1.1.

2.3.1.2.3 *Open-endedness and uncertainty*

Sustainability transitions are open-ended and uncertain (Köhler *et al.*, 2019; Geels *et al.*, 2019; Geels, 2020). Open-endedness and uncertainty characterise GB's electricity transition because transitions in the sector involve the interactions of many different actors as identified in section 2.3.1.1. Moreover, there are many potential innovations in the future and it is difficult to know which one(s) will become mainstream, which means that multiple pathways to futures are possible (Köhler *et al.*, 2019; Geels *et al.*, 2019). These multiple pathways lead to open-ended futures (Geels, 2020). Such open-endedness implies that the outcome of these pathways (i.e. futures) are complex and messy. "*A mess*" refers to complex problems that decision makers need to face and is defined as a system of problems that produces dissatisfaction (Ackoff, 1974, p.5). The term "*mess*" is used in the sense that reality is messy (Law, 2004). A future which contains a tidy arrangement of future elements should not be expected.

Open-endedness and uncertainty also relates to the non-linear nature of innovations which might face technical failures or social resistances (Berkhout, 2002; Berkhout *et al.*, 2004; Shove and Walker, 2007; Köhler *et al.*, 2019). The non-linear process of innovations is relevant to the context of GB's electricity sector (Mitchell, 2008). Innovation is not a "*predicted known outcome from policies*" (Mitchell, 2008, p.42). It means that transitions to a future are not simply planned (Hajer *et al.*, 2015; Geels *et al.*, 2019). Rather, transitions require policy makers to deviate from a simple economic viewpoint which embraces irrational behaviour of consumers to a complex view of transition management for innovations to flourish (Mitchell, 2008; Kern and Smith, 2008). However, it is argued that the current GB's electricity sector does not embrace the non-linear characteristic of innovations (Mitchell, 2008). In other words, the sector does not recognise the open-endedness and uncertainty of transitions which might hinder the effectiveness of transition management of the sector (ibid).

Acknowledging the open-endedness and uncertainty of transition, transition management literature – a strand of transitions research which focussed on targeted transitions (Silveira, 2016) to steer transitions in a more sustainable way (Loorbach, 2010) also recognises that: "*the transition objective is an important element of transition management but does not have to be set in stone*" (Rotmans *et al.*, 2001, p.9). It means that transition objectives/ goals can change overtime as transitions unfold.

2.3.2 Futures in transitions research

This section identifies the role of futures in transitions and reviews literature on identifying futures/ futures pathways/ future scenarios in GB's electricity sector. A gap in knowledge about how futures come about capturing the mess from the interaction of actors in the sector is then identified.

Transitions of GB's electricity sector to sustainability are future-oriented; hence, futures play a key role in transitions. Within research about transitions, anticipating the future is essential for almost all organisations and societies, many of which "*hold the future to be a better guide to what to do in the present*" (Urry, 2016, p.1; Shell, 2018). As such, "*the future*" in transitions research serves as a goal for organisations and societies to work towards.

A popular way to anticipate the future is developing scenarios, i.e. illustrations and interpretations of futures (Urry, 2016). Scenarios are developed by a number of well-known organisations such as Shell or National Grid (Shell, 2018; National Grid, 2019b). According to Rydin (2012), they are plausible snapshots of the future rather than just predictions and forecasts. Developing future scenarios involves developing detailed images of futures together with processes that need to unfold in order for these futures to be realised within a specific time period (Urry, 2016). Scenarios also detail choices that help people prepare for various futures.

In transitions research, these scenarios are usually called socio-technical scenarios or transition pathways. Transition pathways are defined as "*patterns of changes in socio-technical systems unfolding over time that lead to new ways of achieving specific societal functions*" (Turnheim *et al.*, 2015, p.240). Similar to scenarios, these pathways comprise unfolding processes to futures which creates opportunities for intervention (ibid). Pathways are also used as a framing for challenges for transitions to low carbon futures in energy policy (Wiseman *et al.*, 2013; Wise *et al.*, 2014; Rosenbloom, 2017).

Given the key role of future scenarios and transition pathways in transitions research and the industry, many typologies for these scenarios and pathway are proposed. For example, Smith et al (2005) elaborate four pathways: endogenous renewal, re-orientation of trajectories, emergent transformation and purposive transitions based on regime pressures and the coordination of resources available to adapt to these pressures. Geels and Schot (2007) also develop a typology of four pathways: transformation, reconfiguration, technological substitution, and de-alignment and re-alignment which will be looked at in detail in section 2.4.1.2 below. Empirically, multiple scenarios and transition pathways to low carbon future have also been developed, such as in electricity sector (Shackley and Green, 2007; Verbong and Geels, 2010; Foxon, 2013; Geels *et al.*, 2016; Roby and Dibb, 2019; Rogge *et al.*, 2020) or in mobility sector (Marletto, 2014; Geels, 2018b; Köhler *et al.*, 2020), many of which are in the UK context.

Conventionally, future scenarios are criticised for not including "*actor-based approaches*" (Hughes, 2013). In other words, most UK future scenarios or transition pathways in the industry have concentrated on the adoption rates of low-carbon technologies or the cost of technologies added to the system and pay less attention to the role of actors with their interests and motivations in transitions (Foxon, 2013). The Royal Commission on Environmental Pollution (2000) published a report on Energy – The Changing Climate with four possible scenarios for carbon emissions. In 2012, the Challenging Lock-in through Urban Energy System (CLUE) project identified two future scenarios based on drivers, barriers and capacities relevant to deploy local initiatives (Rydin *et al.*, 2012). Moreover, the UK Energy Research Centre (2013) published a range of future scenarios based on carbon emission trajectories, with emission reductions ranging from 40% to 90% by 2050. Also creating possible carbon future scenarios based on the rate of carbon emissions by 2050, the Committee on Climate Change recommended carbon budgets for five-year periods. The latest was the 5th carbon budget covering the period 2028-2032 (CCC, 2015a). The 6th carbon budget is scheduled to be published in Dec 2020. Shell International (2018) considered future scenarios over longer timeframes – 2070 in which the global warming target of well below 2^{o}C is met. The importance of gas, oil and CCS is emphasised in these future scenarios. Energy Networks Association (2018) developed five future worlds for network companies to understand the development of smart grid technology initiative and investigated the infrastructure needed for these worlds. National Grid also made a significant contribution to future scenarios. For example, four future scenarios based on the three key objectives of energy policy (clean, reliability and affordability), which reflected possible sources of and demands for gas and electricity in order to drive debate and decision making in the wider energy industry (National Grid, 2019b).

Other research considers the regulatory and policy implications for transition to a low carbon future in the electricity sector. For example, research about futures of the sector conducted by Energy UK (2019) identified the challenges it is likely to encounter in transition to low carbon futures and set out potential solutions for the regulator and policy makers. These future scenarios from the industry and government bodies are predominantly made by modelling tasks with pre-defined timeframes, dominant technologies and fixed planning objectives. These futures are thus *tidy* and do not reflect real-life activities with social interactions, leading to a call for a more nuanced future making practices taking into account these interactions (Knappe *et al.*, 2019).

Recently, there is more and more research focusing on actors and their roles in transition (e.g. Foxon, 2013; Geels *et al.*, 2020; Rogge *et al.*, 2020). Foxon (2013) suggested that different key actors have different logics for key energy challenges which frame choices and dominate future pathways. This research neatly framed the motivation and interests of different actor constituencies into specific future pathways, abstracted the findings and reduced complexity. The “Market Rulers” pathway speaks to the interests of energy incumbents who want the government to set out policy and then let the market play its role in order to achieve the development of large-scale energy technologies such as CCS, nuclear power, and offshore wind power. The “Central Co-ordination” pathway represents the interests of central government with heavy intervention to support the development of the same types of large-scale energy technologies as “Market Rulers” pathway. The “Thousand Flowers” pathway, in contrast, rests on the interests of new entrants, existing incumbents who are able to shift their strategies and local communities who prefer small scale renewables such as wind power, solar PV. Hence, although pay attention to the roles of actors in transition, each future in this Foxon’s (2013) research speaks to the mutual interests of a specific actor group, and as a consequence, does not include the interaction of actors involved in the transition in each future.

Similarly, two studies from Geels et al (2020) and Rogge et al (2020) explored how interactions of actors can generate dynamics overcoming the “*transition bottlenecks*” (i.e. historical and present contradictions between findings from quantitative model and qualitative analysis) and developed storylines to elaborate two pathways from 2010 to 2050 for the UK and Germany electricity sector, respectively. In both studies, pathway A is led by incumbents with incumbent large-scale low carbon technologies while Pathway B is led by new entrants with smaller-scale technologies. These two studies draw out the interactions between actors for the recent past and present, rather than in the future. As such, future pathways in these two studies are tidy and clearly delineated. Here, the tensions/ contractions/ interactions of actors are assumed to not appear in the future. However, transitions of GB’s electricity sector is uncertain and open-ended, in the sense that they are messy in not only their processes but also their outcomes, i.e. futures (also see section 2.3.1.2). Hence, there is a gap in knowledge of how transitions to futures come about, capturing the messiness arising from the interactions of actors.

2.3.3 A call towards whole system transitions

Transitions in GB's electricity sector are understood to involve multiple changes in the sub-systems of the system, including for instance generation, distribution, consumption and the architecture, institutions and behaviour of actors, in which these reside (McMeekin *et al.*, 2019). Transitions as such should not be considered as removing technological and non-technological barriers (Mazur *et al.*, 2019; Guy and Shove, 2000) or occurring by adding technologies or knowledge (Guy and Shove, 2000; Langendahl, 2012). In other words, transitions are systemic in nature (Gorissen *et al.*, 2018; Schot *et al.*, 2018; Geels, 2018b; Geels *et al.*, 2019; McMeekin *et al.*, 2019). However, current research in transitions tends to emphasise technologies added in separate parts of the electricity sector. For example, in the electricity generation with the breakthrough of solar PVs (Smith et al., 2014), off-shore wind (Kern et al., 2014), nuclear power (Sepulveda, 2016), carbon capture and storage (Shell, 2018). In the above research, each sub-system of the GB's electricity sector is the unit of analysis, rather than the whole of GB's electricity sector.

Notwithstanding, some industrial and policy documents also call for a whole system analysis of the sector. Such whole system analysis approach rejects the idea that a technology can bring about transition to low carbon futures and pays attention to all technologies and their linkages in the system (Energy Technologies Institute, 2017). Whole system analysis also spans the boundary of the electricity system to include transport and heat systems and calls for a more holistic approach to energy policy (Energy UK, 2016), or for the sharing of data across these systems (National Grid, 2019b), or for integrating electric vehicles to the system (Energy Systems Catapult, 2020). Nevertheless, these documents approach the whole system analysis by focusing mainly on technologies and continue to pay limited attention to the role of actors (McMeekin *et al.*, 2019).

In response to the above criticism towards the whole system analysis, McMeekin et al (2019) considered GB's electricity sector as a unit of analysis to study transition of the sector and developed a whole-system analysis of the sector from 1990-2015. This unit of analysis was set so as to encompass national generation, distribution and consumption of GB's electricity sector. This research also paid attention to techno-economic elements (e.g. technologies) and socio-institution elements (e.g. actors) of the sector. However, while this research provided a whole system approach to the analysis of transitions, it has been used to study *historical* developments rather than studying *futures*. Therefore, given the needs to further exploring futures of GB's electricity sector in transitions and to capture the messiness emerging from interaction of actors identified in previous section, another research gap emerges: to make a whole system analysis of these transitions to futures.

2.3.4 Energy flexibility in transitions of GB's electricity sector to a low carbon future

In line with the development of studying low carbon electricity sector futures, the International Energy Agency (2008) realised that researching about energy flexibility has not yet been a common practice. However, with the increase in the percentage of renewables in the generation mix and the need for the electricity system to operate in a stable and secure way, especially in Europe, some further investigation about energy flexibility has been started (Jones, 2014; Expert Group 3 - Smart grid task force, 2015).

GB's electricity sector followed Europe in investigating energy flexibility. The first radical project to develop a strategy to enhance the deployment of new sources of energy flexibility was launched by Ofgem (2015b; 2015c). Their reports outlined some key roles of flexibility in electricity systems:

- Shift consumption to a different period of time
- Reduce demand at key times
- Increase consumption when needed.

With these key roles, energy flexibility could bring benefits to wider society, the electricity system and consumers. Ofgem (2015c) emphasised that measures to increase energy flexibility would not only help to deliver sustainable, reliable and affordable electricity but would also enable consumers to play an active role in the electricity system. The Committee on Climate Change (2015a) also emphasised the importance of energy flexibility in accommodating low carbon generation. Energy flexibility would be used as back-up for wind and solar energy and reduce the risk of excess generation at times of low demand and the need for additional infrastructure to transmit power generated in more remote locations. Moreover, some reports argued that energy flexibility would reduce system integration costs of low carbon generation and thus benefits to the whole economy (Strbac *et al.*, 2015; NIC, 2016; Shakoor *et al.*, 2017). Other reports argued that energy flexibility can reduce costs for the economy, the sector and electricity for consumers (NIC, 2016; 2018; BEIS and Ofgem, 2016). However, these benefits mainly relate to choices made about the use of various low carbon technologies and sources of energy flexibility.

Moving beyond technologies, many studies focused on the importance of the policy implications and transparent market arrangements for energy flexibility. The Committee on Climate Change (2015a) called for the UK Government's to clarify the direction of future policy. Druce *et al.* (2015) considered the prevailing regulatory and market arrangements in the electricity market and suggested that the government should pay attention to all system integration costs when delivering the policy in order to keep the costs to the consumer as low as possible. The National Infrastructure Commission (2016) and Strbac et al (2016b) emphasised the leading role of the government, system operators and Ofgem in creating fair and transparent market arrangements and policies for the uptake of energy flexibility. Poyry and Imperial College London (2017) also called for the leading role of the government, Ofgem and system operators in deploying energy flexibility. The needs for regulatory policy and market arrangement have gained public attention through a joint project between BEIS and Ofgem (2016). BEIS and Ofgem (2017; 2018) developed a plan to support the sector to move towards a smart and flexible electricity system. The Committee on Climate Change (2020) also realised the economic benefits of energy flexibility and suggests that a more detailed plan for achieving such benefits should be set out in The Energy White Paper due in late 2020. However, comparatively little work has been conducted on how transitions to new sources of energy flexibility (demand side flexibility, storage and interconnection) comes about.

The changing sources of energy flexibility in the electricity sector is a subject of growing interest. Realising the potential opportunities and risks associated with the development of new entrants and new business models in transforming the sector, Ofgem (2015a) consulted key stakeholders from the wider industry and has received responses related to the installation and use of generation, storage and demand side response. CGI, in association with Utility Week (2016) conducted a survey with key actors from the sector which indicated that the wider industry agreed about the strategic importance of energy flexibility. Survey respondents rated the opportunities for these key actors' businesses arising from energy flexibility deployment differently depending on their role in the value chain of the sector. However, despite these important contributions, it is fair to say that transitions research has paid limited attention to how the actual processes to new sources of energy flexibility may be developed and unfold. Given the growing interest of energy flexibility in political agendas and the industry, further understanding of the changing sources of energy flexibility in transitions to low carbon futures is needed. Knowledge about transitions to new sources of energy flexibility of GB's electricity sector emerges as a third gap: to understand how transition to new sources of energy flexibility may be achieved.

In summary, section 2.3 identified three gaps in knowledge which are used to articulate the research aim and objectives. They are:

- **Research gap 1:** How transitions to futures come about, capturing the mess emerging from the interaction of sector actor constituencies;
- **Research gap 2:** Whole system analysis of transitions to futures of the sector;
- **Research gap 3:** How transitions to new sources of energy flexibility of GB's electricity sector may be achieved.

In order to address these three gaps of knowledge, a research approach is needed to develop futures which focus on the role of actors. The following sections review various theoretical frameworks which may form the basis of an approach to the research.

2.4 RESEARCH APPROACH

This section looks at the theoretical frameworks to study transitions of the GB's electricity sector to futures, focusing on the interaction of actors. Embedded in transitions research, this section firstly reviews some established transitions theoretical framework, focusing on the usefulness of Multi-level perspective (MLP) in understanding futures and capturing interaction of actors. The notion of architectural innovation and power in transitions research are reviewed to enrich the understanding of whole system transitions. Finally, the rationale for using discourse analytic approaches in general and discourse coalitions in particular in transitions research is explored.

2.4.1 Transition theoretical frameworks

There are several theoretical frameworks available to study transitions. Markard et al (2012) consider Strategic Niche Management (SNM), Transition Management, Multi-Level Perspective (MLP), and Technological Innovation Systems (TIS) to be apposite approaches to study and manage transitions. According to Markard et al (2012), the reason for this selection is because such approaches adopt systemic views of long term socio-technical transformation processes. Lachman (2013) reviews the above approaches and adds Techno-Economic Paradigm (TEP) and Socio-Metabolic Transitions. They are the most notable approaches, which were used often in the field (ibid). Silveira (2016) reviews Techno-Economic, Technological Innovation Systems, Socio-Ecological Transitions, Multi-Level Perspective, Strategic Niche Management, Transition Management, the Reflexive approach, Socio-Practice and Human Geography approaches (see Table A.1 in Appendix A) as the most relevant to study sustainability transitions to a low carbon economy. Among them, the MLP emerges as the core framework to study transitions (Köhler *et al.*, 2019; Geels, 2020). The following section takes a closer look at the Multi-level Perspective and the rationale for using concepts from the MLP to study transitions of GB's electricity sector to low carbon futures.

2.4.1.1 The Multi-level perspective

The MLP is a framework to understand sustainability transitions (Geels, 2010). According to the MLP, transitions come about through the alignment and interaction of dynamics at three different levels: technological niche, socio-technical regime and socio-technical landscape (Rip *et al.*, 1998; Geels, 2002; 2005c; 2011). These different levels form a nested hierarchy including a macro level endogenous landscape, a meso level regime and micro level niches (Geels, 2002). These levels are nested to account for the embedded nature of regimes within landscape and niches within regimes (Figure 2.3) (Geels, 2002). The logic of the three levels is that they provide different kinds of coordination and structuration of activities (Geels, 2005a). The work at the niche level is often geared to the problems of existing regimes (hence the arrows up in Figure 2.3). However, it is not easy for niche novelties to replace the regime because the elements within the regime are linked (hence the connection between regime's elements in Figure 2.3). A closer look at each level begins with the meso level in which transitions happen.

The meso-level: Socio-technical regime

One of the core concepts of socio-technical systems is the socio-technical regime. This is built on the notion of the technological regime developed by Nelson and Winter (1982), who claim that technological regimes comprise cognitive routines (e.g. search heuristics) of engineers that guide their Research & Development activities. In a community of engineers, these cognitive routines arise from the coordination of activities. When engineers share the same routines, they tend to search for new ideas in the same direction. Rip and Kemp (1998) widened the notion of regimes to encompass sociological aspects and define regimes as a "*rule-set*", which means that the regime includes not only engineering communities but also other social groups such as users, scientist, policy makers and societal groups (Geels, 2002; 2005c). Such group activities are guided by rules and are thus, aligned to each other: the alignments of activities create a socio-technical regime (Geels, 2002).

As socio technical regimes are based on rules, they are characterised by stability (Geels, 2002; Geels and Schot, 2010). The stability refers to the "*lock-in*" to the existing energy system because of "*sunk investments, behavioural patterns, vested interests, infrastructure, favourable subsidies and regulations*" (Unruh, 2000). For example, because of sunk investment, firms want to stick with

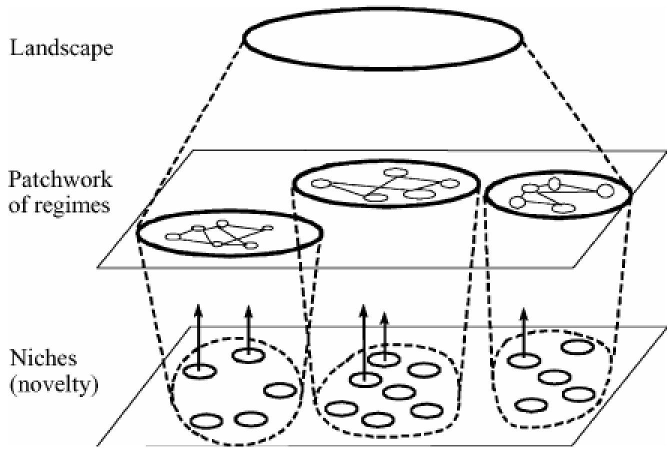


Figure 2.3: Multi-level as a nested hierarchy (Geels, 2002)

established technology paths. However, this stability is dynamic, which means that innovations can occur incrementally in the regime, leading to particular paths or trajectories (Geels, 2005a; Geels and Schot, 2010). These trajectories can occur in not only technology, but also in other sub-systems such as cultural, politic, scientific, market and industrial dimensions (Geels, 2011). Different trajectories are carried and used by different social groups (Geels, 2005a). These groups are interdependent and interacting with each other (Geels, 2005a) which makes different trajectories coevolve (Figure 2.4) (Geels and Schot, 2010). Changes in one trajectory may dampen the linkages between them, resulting in tensions and create windows of opportunity for transitions (Geels and Schot, 2010).

The micro-level: Technological niches

Another important aspect of sociotechnical transitions is technological niches. Niches are defined as protected spaces or incumbent rooms for radical innovations to develop and protect them from selection pressures emanating from the regime (Kemp *et al.*, 1998; Markard *et al.*, 2012) . Niches are important because they provide spaces for learning and enable networks supporting innovations to be built (Geels, 2002). As such, they provide the "*seeds*" for transitions (Geels, 2011). However, niche innovations do not replace the regime easily because (1) the regime is stabilised by lock-in mechanisms and (2) niche innovations are not closely aligned (lack of infrastructure, regulations, users practices) with existing regimes (Geels, 2011).

The macro-level: Socio-technical landscapes

Socio-technical landscape refers to the "*exogenous environment*" which impacts socio technical development but it is not directly impacted by the regimes and the niches (Geels and Schot, 2010; Geels, 2005a). Socio-technical landscapes include heterogeneous factors such as oil price, wars, environmental problems (Geels, 2002). There might be multiple landscape pressures, such as in the

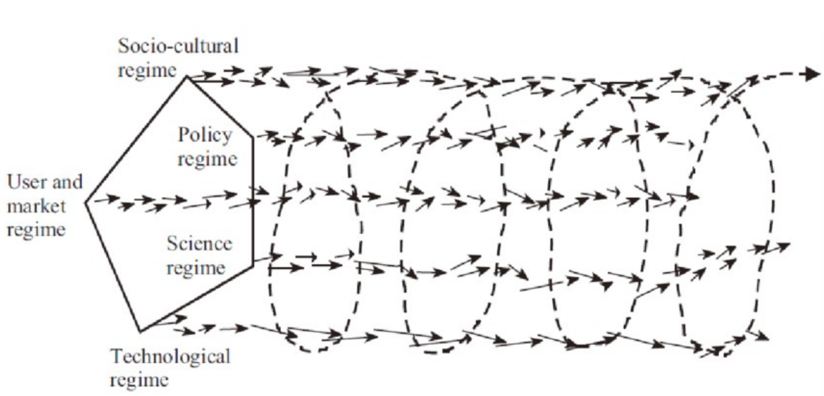


Figure 2.4: Co-evolution between multiple trajectories in a socio-technical regime - adapted from (Geels, 2004)

UK mobility sector (Geels, 2018b) where these landscape pressures are "*endogenised through political struggles*" of actors (Rosenbloom *et al.*, 2016, p.12).

A number of the above characteristics can be summarised to highlight the differences in these three levels:

- The regime refers to rules while the landscape refers to wider external factors (Geels, 2002).
- The regime generates incremental innovations while the niche generates radical innovations (Geels, 2002).
- The landscape is more stable than the regime and the regime is more stable than the niches in terms of number of actors and degrees of alignment between the elements (Geels, 2011).

The interplay between these three levels which bring about transitions have been described in four phases (see Figure 2.5) (Geels, 2005a).

Phase 1: Emergence of novelty

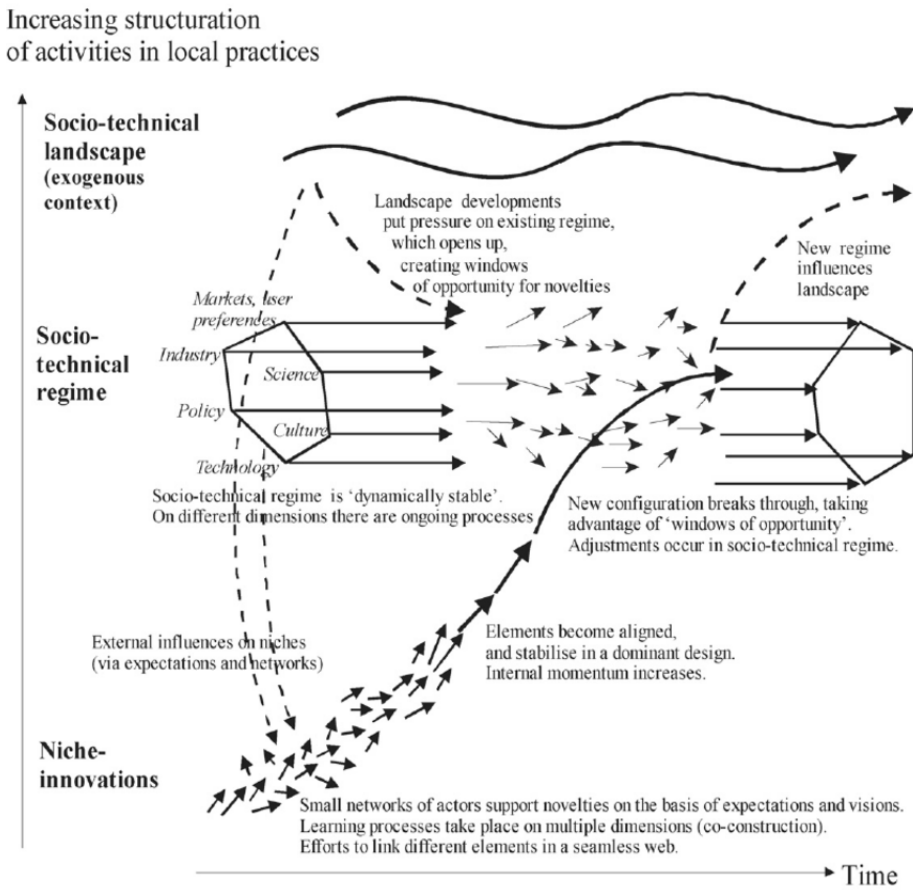


Figure 2.5: Multi-Level Perspective on transitions (Geels, 2002)

Novelties emerge in the niches and compete with each other. No novelty is dominant in the niche yet.

Phase 2: Development in small market niches

Engineers at the niche level direct their activities towards a specific novelty. They develop new rules which create a technical trajectory for the novelty. Then, the novelty can explore new functionalities through learning process and networks, which result in the stabilisation of rules, e.g. dominant design.

Phase 3: Breakthrough of the new technology, wide diffusion, competition with the regime.

The novelty, which has gained momentum in Phase 2, has a chance to breakthrough to the regime. The breakthrough happens because of the landscape pressure, creating tensions in the regime and opening windows of opportunity and creating internal pressure for breakthrough such as price/performance improvement. After breaking through to the regime, the novelty can compete directly with the existing regime.

Phase 4: Gradual replacement of the regime

This phase involves the replacement of the old regime by a new technology, which is accompanied by changes on other sub-regimes of the socio-technical regime such as society, policy, culture, market and user practices.

2.4.1.2 Developing futures using the MLP

Futures or transition pathways arise from the interaction between the internal dynamics of regime, the wider landscape and niche novelties, which destabilises the incumbent regime and may engender a new one (Foxon *et al.*, 2010). Drawing on the MLP, Geels and Schot (2007) have developed a typology of socio-technical transition pathways based on the timing and nature of the multi-level interactions and types of landscape change. In terms of the nature of interactions, landscape pressures may reinforce or disrupt interactions with the regime; niche innovations may have a competitive relationship or symbiotic relationship with the regime. The nature of interactions can either replace or enhance the regime (Geels and Schot, 2010). Niche innovations are ready to breakthrough to the regime only if some of the following phenomena arise (Geels and Schot, 2010):

- Learning process stabilised in a dominated design
- Powerful actors joined the supporting network

- Price/performance improvements have occurred and there are strong expectations of further improvement
- The innovation is used in market niches, which cumulatively amount to more than 5% (this percentage is only an approximate figure).

As well as timing, different types of the pressure from the exogenous landscape may also create different outcomes. They include regular (low intensity and gradual change), hyper turbulence (a high frequency of high-speed change in one dimension), specific shock (rapid and high in intensity), disruptive (high intensity effect on one dimensions), avalanche (infrequently, high intensity, high speed and on multiple dimensions) (Figure 2.6) (Suarez and Oliva, 2005; Geels and Schot, 2007). Based on the timing and nature of the multi-level interactions and types of landscape change, four transition pathways are described as below (Geels and Schot, 2007):

Transformation pathway: This pathway features a disruptive landscape pressure on the regime, but niche innovations are not well established. Regime insiders tend to neglect the pressure while regime outsiders translate it and draw insiders' attention to the negative aspects of the regime. Outsiders could be firms who develop alternative practices. Outsiders can also be engineers who criticise the current technology or pressure groups who protest and mobilise public opinions. Gradually, the perception of insiders' changes and new regimes grow out of the old one through cumulative adjustments and reorientations. In this pathway, regime actors survive as they only need to change the direction of innovation activities (Geels and Schot, 2007).

De-alignment and re-alignment pathway: If the landscape creates pressure in multiple dimensions (avalanche pressure), regime actors may lose faith in the existing regime, which brings about the de-alignment of the existing regime. However, niche-innovations are not fully developed to take

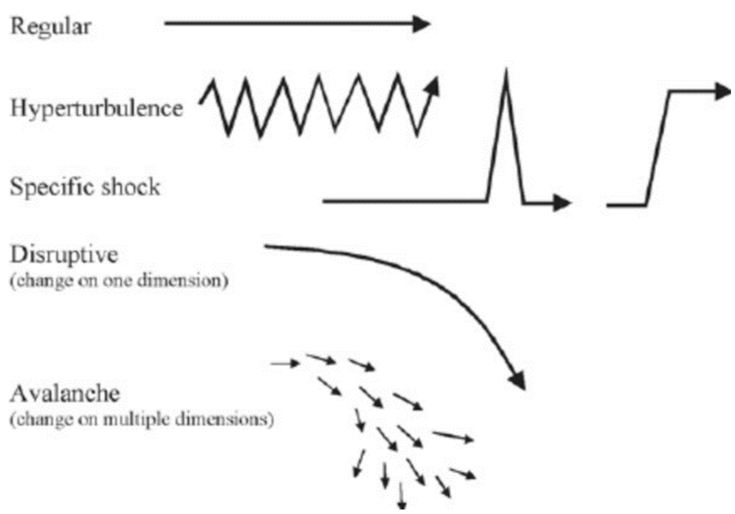


Figure 2.6: Types of environmental change (Suarez and Oliva, 2005)

advantage of this window of opportunity. At the niche level, niche innovations co-exist and compete. Then, one niche level innovation becomes dominant, is ready to breakthrough to the regime, and causes re-alignment of the new regime (Geels and Schot, 2007).

Technological substitution pathway: The niche innovations in this pathway have been sufficiently developed in niches. However, the regimes are so stable that niche innovations remain stuck in niches. This pathway occurs when there is a combination of landscape pressure including specific shock, avalanche and disruptive change, which create major tensions in the regime. Niche innovations then have an opportunity to breakthrough to compete with existing regime and cause a wider regime change (Geels and Schot, 2007).

Reconfiguration pathway: The disruptive pressure from the landscape urge regimes to change. At this time, multiple niche innovations are well established but they are symbiotic innovations. Thus, they are easily adopted by regimes to resolve regime problems. Acting at the regime level, these novelties trigger more adjustments and lead to the regime transitions (Geels and Schot, 2007).

These future pathways have been used to demonstrate historical transitions (Geels, 2002; 2005c; Berkers and Geels, 2011; Geels *et al.*, 2016; McMeekin *et al.*, 2019). They have also been used by some scholars to identify future transition pathways (Shackley and Green, 2007; Verbong and Geels, 2010; Geels *et al.*, 2020; Rogge *et al.*, 2020). However, Geels et al (2016) realised that these pathways pay limited attention to the actors and suggested a reformulation of these pathways to focus on actors.

In the *transformation pathway*, incumbent actors may re-orient towards radical niche-innovations including not only new technologies but also new beliefs, missions, and business models. In the *de-alignment and re-alignment* pathway, incumbents are collapsed due to the landscape pressure which creates a chance for new entrants to replace incumbents. In the *substitution pathway*, radical new entrants struggle against incumbents and substitute the regime. New entrants here can be community energy or incumbents from different sectors. In the *reconfiguration pathway*, new alliances between incumbents and new entrants are formed. This typology of transition pathways suggests that the concepts from the MLP open up space for analysing the interaction of actors in futures. In the next section, the rationale for using the concepts from the MLP in this study is described in detail.

2.4.1.3 Rationale for using concepts from the MLP

The ideas and concepts from the MLP are useful in this study firstly because the MLP is the most widely-used framework to anticipate futures and to study transitions in GB’s electricity sector to low carbon futures. There is a considerable amount of empirical research which has used the MLP.

In Google Scholar, there are 5352 citations for the foundational paper of the MLP (Geels, 2002) by August 2020. Foxon et al (2010) used the MLP to approach three different future pathways of GB's electricity sector to 2030. Verbong and Geels (2010) used the MLP to develop infrastructure transition pathways of the UK electricity systems. Geels et al (2020) elaborated two future pathways of the UK electricity sector from 2010 to 2050 which bridge the gaps between modelling and socio-technical analysis. The latest paper looking at whole system analysis of transitions of GB's electricity sector is also drawn on the MLP framework (McMeekin *et al.*, 2019).

Moreover, the MLP has started to be used to inform policy. The UK Government Cabinet Office for COP26 (The 2021 United Nations Climate Change Conference) has planned their actions based on transitions research frameworks, in particular the MLP (Victor *et al.*, 2019). The European Environment Agency explores how the governments within European and regional countries can respond to the challenges of transitions to sustainability, with insights from the MLP (Geels *et al.*, 2019). Rogge et al (2020) identified transformative policy mixes to inform the German government of transition governance.

Most importantly, although this study aims to address the gap of motivations of actors or agency (the capacities of actors to take actions (Giddens, 1984; Smith *et al.*, 2005; Geels, 2020)), agency should always be "*agency towards somethings*" (Geels, 2020). In other words, transitions should focus on actors in relationship with a particular context or structure. As such, the ideas and concepts of the MLP, which not only focuses on landscape/regime/niche structure but also open up a space to focus on the role of actors, is relevant to the research objectives of developing futures where the actors play an important role. In the MLP, both niches and regimes have the character of a "*community of interacting groups*" (Geels and Schot, 2007). Both niche and regime communities share certain rules. The difference is that rules in regimes are more stable than rules in niches. Underlying these rules are actors who are not only guided by rules but also use and make rules (as described in 2.3.1.1). The ideas and concepts of the MLP are useful to explore the interactions of actors in transitions to a low carbon future of GB's electricity sector**.**

2.4.1.4 Transitions research ontology and epistemology

Research ontology and epistemology refers to the underlying assumptions of transitions research about "*nature of the world*" and "*nature of knowledge*" (Stainton-Rogers, 2006). Studying these assumptions are important because they impact how knowledge about futures of the sector is understood. This section reviews research ontologies and epistemologies of transitions research, in particular the MLP (see section 3.2.2 for further discussion and the chosen ontologies and epistemologies of this study).

The MLP is rooted in several theoretical foundations on socio-technical transitions including Social Construction of Technology (SCOT), evolutionary economics and neo-institutional theory (Geels, 2020). These theories conceptualise transitions and agency differently, depending their ontological assumptions underlying these theories (Table A.2 in Appendix A demonstrates these differences) (Geels, 2020). In summary:

- Neo-institutional theory tends to be based on *structuralism* (actors enact taken-for-granted belief systems and deep structures) (Geels, 2020).
- SCOT tends to be based on *interpretivism* (sense-making, social construction of meaning)
- Evolutionary economics tends to be based on conflict and *power* struggle (collective groups struggle over material interests) and *rational choice* (individualist).

The MLP is "*not a theory of everything*" (Geels, 2020, p.12) but a middle-range theory combining a limited set of interrelated propositions to understand delimited aspects of social phenomena at empirical level (Geels, 2007). Hence, making crossovers between different theories and ontologies is possible. There are some attempts to do so (Geels, 2010; 2020). The MLP makes crossovers to interpretivism/constructionism, structuralism and power, but not rational choice (Geels, 2010). These ontologies are considered below.

Genus and Coles (2008) suggested that the MLP incorporates SCOT; hence, interpretivism/ constructionism should always be part of the MLP (Geels, 2010). Constructionism is more agency-oriented than structuralism. According to constructionism, actors have various ideas and they are continuously engaged in sense-making and interact with each other through debates, negotiations, conversations and learning processes (Geels, 2010). Such interactions are ongoing-processes and engender transitions. As this study pays attention to addressing a gap in knowledge about the role and interactions of human actors, a "*future of GB's electricity sector*" is a social product. A "*future*" is produced through the interaction of human actors arguing and defining the possible futures of the sector in particular ways. In other words, futures are socially constructed. A social constructionism ontological foundation of the MLP is hence relevant in this study.

The MLP always accommodates structuralism because the MLP emphasises the structure of landscape, regime and niches which interact and give rise to transitions. According to structuralism, actors are part of social collectives and share "*cognitive deep structures*" or belief systems (Geels, 2010). It means that actors' capacities to act (i.e. agency) are guided by rules (Geels, 2004). These rules influence how transitions are shaped and define what are desirable and acceptable transitions. However, rooting from structuralism, the MLP has been criticised for lacking the focus on agency and further analysis on agency are emphasised (Smith *et al.*, 2005). Here, the MLP should be enriched by the constructionism perspective of discourse theory (Geels, 2010; Geels and Verhees, 2011). Discourses not only contain "*deep structure elements*" but also an ongoing process of actors' sense-making. Discourses in transitions research are looked at in section 2.4.4.

Avelino (2011) argued that power should not be considered as an ontology separated from other ontologies in social science. Rather, power is embedded in other ontologies in different ways. Power is considered in section 2.4.3.

Geels (2010) suggested that the MLP makes no any crossovers to rational choice. In economics, rational actors are assumed to be "*well-informed*" and "*seek to maximise their personal satisfaction or utility*" (Lipsey and Chrystal, 2015, p.281). Actors are self-interested and "*try to calculate which actions will be best achieve their goals*" (Geels and Schot, 2007, p.403). Rational choice is well established in economic theory to understand individual decision making from a realist view (Lipsey and Chrystal, 2015). In addition to rational choice assumption, realism considers transitions and innovation journeys towards transitions as linear processes to a pre-defined goal (e.g. sustainability) and can be easily achieved by removing non-technological barriers (Guy and Shove, 2000; Langendahl, 2012). These assumptions are used in literature from both academia and the industry in order to provide policy makers with a steer of transition management (Foxon *et al.*, 2005; CCC, 2015b; Engelken *et al.*, 2016; Ofgem, 2016; Shakoor *et al.*, 2017; Energy UK, 2019; CCC, 2019). For example, the Committee on Climate change – Net Zero report (2019, p.16) recommends that "*Policies must be designed with businesses and consumers in mind. They must be stable, long-term and investable. The public must be engaged, and other key barriers such as low availability of necessary skills must be addressed*". These realist assumptions overlook the actual processes in which innovations and ultimately transitions might occur because innovations is "*a messy process in which arrangements are built between actors to support the innovation in very specific time and space contexts*" (Beveridge and Guy, 2005, p.675). Innovations and transitions are considered as messy, complex, non-linear processes emerging through the multi-dimensional and multi-actor interaction (see section 2.3.1.2). Therefore, realism provides limited insights into transitions research agenda.

Sorrell (2018) criticised the MLP because it is not compatible with realism, including critical realism ontology because of the "*ambiguous and unhelpful distinction between systems and regimes"* (Sorrell, 2018, p.14). System includes tangible elements while regime combines of intangible and underlying deep structures (Geels, 2011). However, the MLP does not "*deny the possibility of rational choice*" (Geels, 2010). One of the theoretical foundations of the MLP which is evolutionary theory is based on rational choice assumption (Geels, 2020). Rational choice can reflect the assumptions of regime actors during stable periods, e.g. with stable regulation and dominant design of technologies, investment can be based on cost-benefit analysis (Geels, 2010). As such, rational choice offers little insights into the interactions of actors at regime and niche but should not be excluded from the MLP. Therefore, while realism does not contribute to transitions research as much as structuralism and constructionism, the MLP can *accommodate* realism.

Although the ideas and concepts from the MLP are relevant to help address the lacunae highlighted in this study (e.g. explore transitions of the sector focusing on the roles of actors), they conventionally are used to explore the development of radical innovations in generation or consumption subsystem (e.g. Kern *et al.*, 2014; Smith *et al.*, 2014; Geels *et al.*, 2016). As such, the conventional approach of the MLP seems to be insufficient and fails to explore the transitions of the sector as a whole, especially the interactions of the variety of actors in GB's electricity sector, spanning across all sub-system comparing the sector: generation, distribution and consumption. The following section looks at the notion of architectural innovation which is also useful in approaching the whole system analysis in transitions research.

2.4.2 Architectural innovation

Transitions of GB's electricity sector to low carbon futures involve major changes in not only technologies, but also its architecture, institution and the behaviour of actors (Geels, 2004). However, current research in transitions only focus on innovations in some separate parts of the sector as identified in section 2.2.3. As such, further investigation into whole system analysis is required. This section explores the usefulness of the concepts of architectural innovation in whole system transitions research.

Transitions at societal functions such as electricity sector are conceptualised as "*a change from a socio-technical system to another*" or "*system innovations*" (Geels, 2005a; 2005b, p.2). System approaches to innovations focus on the architecture of the system or the linkages between elements (including social networks involved in innovations) rather than just technology (Geels, 2005b). In other words, these linkages present not only the relationship between technological elements but also between technologies and users.

Several typologies of innovations exist to show how different types of innovations may affect these linkages and engender changes. For example, Anderson and Clark (1985) developed the typology based on two dimensions (1) the linkages between customers and firms and (2) technology and firms. In their typology, architectural innovation comprises of changes in both technology and the firms' linkages with customers, leading to disruptive changes in firms.

Henderson and Clark (1990) also showed a typology in which four types of innovations are identified at firm level (Table 2.1). According to this typology, each type of innovations is defined as below:

Table 2.1: A typology for defining innovations (Henderson and Clark, 1990)

Linkages between Core concepts and components		Core concepts	
		Reinforced	Overturned
	Unchanged	Incremental innovation	Modular innovation
	Changed	Architectural innovation	Radical innovation

- Incremental innovation is technological innovation which involves small technological improvements but does not impact the dominant design or architecture of the technology.
- Radical innovation involves large changes which impact both the core concept of a technology and the linkages between different components of a technology.
- Modular innovation involves change in a core component of a technology but does not impact the linkages between different components of a product, e.g. the replacement of analog with digital telephones.
- Architectural innovation involves changes in the linkages of components, but the core design concept of each component remains the same. However, it does not mean that the components themselves do not change. Architectural innovation is often triggered by a change in a component, for example in size, but not in the core design concept.

However, GB's electricity sector is also argued to experience multiple innovations rather than a single radical niche innovation as in Henderson and Clark's typology (Geels, 2018a; McMeekin *et al.*, 2019). Moreover, although these typologies are useful in terms of system linkages and architecture, they are limited to an organisation focus. At societal function level, transitions/system innovations occur at much wider scale, i.e. involve changes in linkages between technology and technological users but also among network infrastructure, policies and regulation and so on (see section 2.3.1.1). Therefore, transitions/ system innovations can be deemed as "*architectural innovations writ large*" (Geels, 2005b, p.6). Here, architectural innovation plays a key role in giving rise to socio-technical transitions at societal function level including transitions of GB's electricity sector.

GB's electricity sector is defined as a loosely coupled system of sub-systems (conventionally generation, distribution and consumption), which loosely link with other sub-systems and maintain "*a high degree of distinctiveness in terms of technologies, actors and institutions*" (McMeekin *et al.*, 2019, p.1217). This loose coupling allows modular innovations (in Henderson and Clark's typology) to develop in each sub-system and maintain the architecture of the system (Simon, 1977). As such, GB's electricity sector was reconfigured from modular incrementalism (1990-2002) to modular substitution (2003-2009) to architectural stretching (2010-2014) and is expected to experience architectural reshaping from 2015 (McMeekin *et al.*, 2019). These elements are shown in a typology (Table 2.2) adapted from Henderson and Clark's typology and defined below:

- Modular incrementalism: Incremental innovations with existing technologies such as home appliances are innovated with more efficiency.
- Modular substitution: Innovations in parts of the whole system, for example changes from coal to gas in generation
- Architectural stretching: Incremental changes to the logics of system linkages such as network expansion to accommodate new electricity demand.
- Architectural reshaping: Fundamental changes to the logics of system linkages such as smart grids, storage, demand side response.

This typology together with the definition of GB's electricity sector as a loosely coupled system goes beyond the conventional approach of regimes overthrown by radical niche innovations and is relevant to system reconfiguration pathway of Geels and Schot (2007) (see this typology in section 2.4.1.2) (McMeekin *et al.*, 2019). In reconfiguration processes, linkages between sub-systems may change, leading to a "*new whole-system architecture*" (McMeekin *et al.*, 2019, p.1218). Although reconfiguration pathway and architectural innovation have received increasingly attention recently (Berkers and Geels, 2011; Geels *et al.*, 2015; Geels, 2018a; 2018b; McMeekin *et al.*, 2019), most of research paid comparatively little attention to architectural innovation in GB context. Therefore, there is a need to further explore innovations impacting system linkages, i.e. architectural innovation in whole system analysis in GB's electricity sector in its transitions to low carbon futures.

Having considered architectural innovation as important elements for whole-system transitions research, the following section considers the notion of power to understand whole system transitions in terms of the interaction of actors.

Table 2.2: A typology of innovations - adapted from McMeekin et al (2019)

		Core concepts	
		Reinforced	Substituted
Linkages between system components	Unchanged	Modular incrementalism Incremental innovations with existing technologies	Modular substitution Innovations in parts of the whole system
	Changed	Architectural stretching Incremental changes to system linkages	Architectural reshaping Fundamental changes to the logic of linkages

2.4.3 Power in transitions research

It is evident that actors do not have equal power which leaves room for power struggles, i.e. politics (Geels, 2004). Thus, exploring power in transition is needed to understand how transitions come about in terms of the interaction of actors. This section explores how power is conceptualised in transitions research and its contribution to understand whole system transitions.

The conceptualisation of power is contested among transition scholars (Cashmore, 2018). As such, Cashmore (2018) summarised three main types of power conceptualisation. They are (1) power "*to*" and power "*over*", (2) power as coercion and consensus and (3) power as productive force. Each is examined in turn.

Traditionally, power is defined as "capacity" (Avelino and Rotmans, 2009; Cashmore, 2018) following Parson (1967). Seen in this way, power exists "to" achieve a goal (Avelino, 2017; Cashmore, 2018). This way of thinking emphases the conventional approach in power of actors in transition where regime actors have more power than niche actors; hence, can mobilise more resources to harness power "to". Avelino and Rotmans (2009) deviated from power "to" and suggested regimes might not have more power over niches because niches mobilise different resources from regimes. Seen in this way, power is constructed relationally and is referred as power "over". However, power "over" does not go beyond "the ability of actors" (Avelino and Rotmans, 2009). As such, both power "to" and power "over" are about capacities of actors or agency.

The second way of conceptualising power is considering power as coercion and consensus. This school of thought relates to the debate about whether power is collective or distributive (Avelino and Rotmans, 2009). Coercive power goes in line with the belief that outcomes can be achieved through some forms of threat (Cashmore, 2018). Conversely, power is consensus in the sense that power can only be exercised when it is legitimated through consents from society (Cashmore, 2018). As such, consensus power depends on shared norms, values and beliefs of actors (ibid).

However, by conceptualising power as power of actors without relating the notion of power to the structure of the system, i.e. system architecture, transitions research may fail to understand the whole system transitions of GB's electricity sector. Actors and their capacities to act (i.e. agency) are shaped by structural contexts such as cultural context, social context, economic context and regulatory context (Emirbayer and Mische, 1998; Geels, 2020). Transitions as such involve not only agency but also agency in the relationship with other actors and structure (Geels, 2020). Here, the third school of thought in power offers insights by defining power as a productive force. This way of thinking follows Foucault (2002) in which power is exercised rather than possessed by actors. Power is a "*social dynamic that is both enabling and impeding, revealing and obscuring*" (Cashmore, 2018, p.23). Reality can only be produced or reproduced through power of structuring actions around particular norms, aspirations and beliefs to gain legitimacy. Seen in this way, actors rather than just resources can be mobilised. This approach aligns with STS (Science, Technology and Society) research in advocating the co-production and interactions between humans, technology and nature (Ahlborg, 2017). This approach of power is built on constructivist ontology which is relevant to this study (see section 3.2.2). Therefore, considering power as a productive force in transitions broadens the understanding of whole system transitions.

Power of discourses is also important in enriching knowledge on energy transitions. The following section considers the use of discourses in transitions research.

2.4.4 Discourses in transitions research

Actors relate to power while *"power becomes a question of the representation of problems (and solutions) and competition over which representations (discourses) constitute reality, or viable alternative realities"* (Hajer, 1995). Studying discourses and their power then becomes useful to understand the interaction of actors in transitions of GB's electricity sector to future. This section firstly identifies the role of discourses in transitions research. Secondly, the argumentative turn of using discourses and the concept of discourse coalition are reviewed in exploring the interaction of different actors with different arguments about transitions to futures.

2.4.4.1 The role of discourses in transitions research

Discourse represents a "*shared way of apprehending the world*" (Dryzek, 1997, p.8). Different actors' perspectives or assumptions, which refers to different understandings of a regime, influence actors' recognition of regime change and consequently shape the way they form coalitions and "*agree over the best course of action for the regime*" (Smith *et al.*, 2005, p.1503). Hence, in order to understand the changes needed to bring about a regime's transition, different discourses associated with regime change and different visions and expectations about regime futures should be considered (ibid). For example, in case of UK Carbon Trust policy initiative (Kern, 2012), business actors and civil servants formed a coalition and complemented the dominant market efficiency discourse, which both enabled and constrained new policy initiatives.

Geels (2011) also considered the significance of discourses and suggested that cultural sociology and discourse analysis are useful in studying transitions (in the historical case of nuclear energy in the Netherlands) by addressing cultural interactions which mediate niche, regime and landscape interactions. From a structuralist point of view, culture is "*a cognitive deep structure that consists of people's perception of reality and provides a frame of meaning within which people act*" (Geels and Verhees, 2011, p.912). Adding sociological dimensions, discourses focus on collective meanings and sense-making of actors around specific issues (ibid). Collective sense making is an ongoing process involving multiple actors debating issues, e.g. the development of technologies, the changes of an industry. Meanings, which are produced, provide the context for the next round of collective sense making processes (ibid). Discourses are defined as "*an ensemble of ideas, concepts and categorizations through which meaning is allocated to social and physical phenomena, and which is produced and reproduces in an identifiable set of practice*s" (Hajer and Uitermark, 2008, p.7). A discursive approach to studying cultural interactions in transitions is described in Figure 2.7. This approach emphasised the interactions of structure and actors in power of discourses and as such, is relevant to the conceptualisation of power as a productive force described in section 2.4.3.

Discourses contain deep structural elements which are framed by actors (Geels, 2010). Actors draw on and frame discourses to suit their interests. Actors engage in discursive struggles because discourses can influence how audiences think and talk about the issues at hand, which may also influence politics and economics such as political support and financial resources (Geels, 2010).

Scholars have argued for the role of discourses in environmental issues such as acid rain (Hajer, 1995), global ozone layer (Litfin, 1994), climate change (Urry, 2016) as well as in a bigger picture of dominant environmental discourses such as Dryzek (1997), Everett et al (2012), Urry (2016). Other scholars used discourses to enrich analysis of transitions in general and sustainable transitions in particular. Walker and Cook (2009) considered the struggle between different competing discourses which shape sustainable aviation policy. Geels and Verhees (2011) developed a cultural perspective using discourse analysis to analyse transitions to nuclear power in the Netherlands in the period 1945-1986. Scrase and Ockwell (2010) used a discourse perspective to analyse the central goals of UK energy policy: access, security, efficiency and environmental acceptability and argue for a reframing of energy policy in order to override the powerful discourses which dominate the sector. Leipprand et al (2017) described discourses of energy policy in Germany parliament.

Understanding different discourses and their power to affect regime change therefore should be considered when studying transitions to low carbon futures. This knowledge acquisition process is

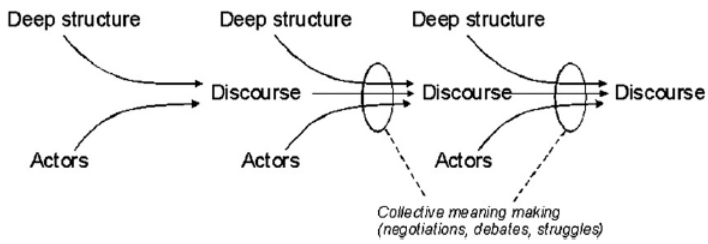


Figure 2.7: Discursive approach to cultural interactions in transitions (Geels and Verhees, 2011)

suitable to apply into GB's electricity sector as the sector has many actors (from both regime and niche levels) who frame transition discourses and join discursive struggles in order to gain political and economic influence. Historically, actors within GB's electricity sector used discourses to shape what is being discussed and how issues are discussed to resist change (Geels *et al.*, 2014). However, these discourses are mainly used to analyse energy policies in transitions at national level (Isoaho and Karhunmaa, 2019), rather than to understand transitions to futures. Therefore, although discourses have been increasingly used in transitions research to emphasise the role of agency, transitions research paid limited attention to using discourses in enriching the knowledge of the sector about transitions.

The following section looks at the argumentative turns in using discourses which is relevant to use in the context of transitions of GB's electricity sector.

2.4.4.2 The argumentative turn of using discourses – Discourse coalition

Discourse "*enables those who subscribe to it to interpret bits of information and put them together into coherent stories or accounts*" (Dryzek, 1997, p.8). Coherent stories refer to transitions to futures of GB's electricity sector in this study. Stories or narratives are told by actors (Harré *et al.*, 1999) which means that these stories or narratives can be a "*device for actors to be positioned*" (Hajer, 1995). In the example of acid rain Hajer (1995) investigated, through narratives, actors were positioned as victims of pollution, as problem solvers, as perpetrators, as top scientists, or as scaremongers. Different actors may have different ideas on regime development and thus, adapt different degrees of influence in building visions of futures. "*Guiding visions*" or "*codified representations of technological expectations*" are able to frame problems and mobilise actors to seek solution to resolve them (Brown *et al.*, 2000; Smith *et al.*, 2005). Expectations are "*real time representations of future technical situations and capabilities*" and are "*insightful enactments of desired future*" (Hubble, 2015) which represent not only "*statements about the future*" (van Lente, 2012) but also "*key drivers*" for technological change (van Lente, 1993). As such, stories told by a group of actors with the same "*position*" or "*interest*" in GB's electricity sector not only reveal what the futures are but also how these futures are constructed.

However, Hajer (1993) suggested an argumentative turn of discourses and argues that it would be misleading to understand a story which contains many complex different arguments (i.e. in an argumentative context) by identifying only one position without understanding counter-positions. GB's electricity sector as highlighted in previous sections comprises many elements and actors. These actors, with many positions and interests, form an argumentative context and can contribute differently to the visions of futures of the sector. These actors might seek to enrol different actors in the coalition of change (Soutar and Mitchell, 2018) as hardly anybody can understand all the details of the futures, as in the case of acid rain (Hajer, 1995). A notion of discourse coalition is useful in applying discourse theories in such context of GB's electricity sector.

A discourse coalition is defined as a "*group of actors who share a social construct*" (Hajer, 1993, p.43). These actors may hold different arguments but have a similar way of conceptualising the world (ibid). This discourse coalition approach suggests that some actors in GB's electricity sector share a similar way of conceptualising transitions to futures of the sector (i.e. assumptions about how transitions may occur), although holding different arguments to support these assumptions. These actors are from various backgrounds, i.e. may hold different positions or interests. Here, transitions and futures of the sector contain various actors' interests and interactions of these actors who "*try to impose their view of reality on others*" and "*criticise alternative social arrangements*" (Hajer, 1993, p.47). A discourse coalition approach is thus useful in capturing the mess emerging from the interactions of actors who do not necessarily have shared interests in transitions of the sector.

This section justified the role of discourses and discourse coalition in enriching the understandings of transitions research and capturing the mess from the interaction of actors. Some contemporary energy discourses which potentially form discourse coalitions in the electricity sector have been identified from the literature (section 2.6.2). Identifying contemporary energy discourses in literature will assist discourse analysis of data in this study.

The following section concludes and restates the research aim and objectives.

2.5 CONCLUSIONS

2.5.1 Some key findings from the literature

This literature review explores the historical development of GB's electricity sector starting from the initial objective of ensuring electricity security of supply to 'keep the lights on' by balancing supply and variable demand and the challenge of meeting this objective as part of transitions to local carbon futures. The challenge is shaped by the reduction in the quick start-up fossil fuel power plants and the increase in intermittent renewables and inflexible nuclear power. Maintaining the level of energy flexibility is expected from new sources of flexibility such as demand side flexibility, storage and interconnection. Together with the development of the current 4Ds context (decarbonisation, decentralisation, digitisation and democratisation), the changes to new sources of energy flexibility become attractive.

In response to climate change, GB's electricity sector, formed of three sub-systems: generation, distribution and consumption, needs to transition to a low carbon future. Conceptualised as socio-technical transitions to sustainability, several relevant characteristics of sustainability transitions are identified, including (1) involve multi-dimensional and multi-actor processes, (2) involve both changes and stability and (3) are open-ended and uncertain. Such transitions involve multiple pathways leading to messy futures. The term "mess" is used in the sense that reality is messy (Ackoff, 1974; Law, 2004). Hence, transition is not a linear process to a pre-defined goal and might not be simply 'planned'.

Futures play a key role in transitions. A popular way to anticipate futures is developing socio-technical scenarios or transition pathways, which comprise of unfolding processes to futures which creates opportunities for intervention (Turnheim *et al.*, 2015). Scenarios or pathways are also used as a framing for challenges for transitions to low carbon futures in energy policy (Wiseman *et al.*, 2013; Wise *et al.*, 2014; Rosenbloom, 2017). Given the key role of these socio-technical scenarios or transition pathways, many studies in transitions research and the industry identify typologies for transition pathways as well as develop empirical futures. Most of the UK research on futures have concentrated on the adoption rates of low-carbon technologies needed, the cost added to the total system cost or the regulatory and policy implications with relatively little discussion of the motivations of actors involved (Hughes, 2013; Foxon, 2013). Some studies started to steer the focus on actors with their different interests and motivations (e.g. Foxon, 2013; Geels *et al.*, 2020; Rogge *et al.*, 2020). However, these studies pay attention to the interactions of actors in the past and present to elaborate tidy futures. In other words, these studies fail to capture the mess of futures emerging from the interactions of these actors in futures. As such, there is a gap in knowledge (***research gap 1***) of how futures come about, capturing the mess of futures emerging through the interaction of sector actor constituencies.

Transitions of GB's electricity sector can be understood as changes spanning generation, distribution and consumption sub-systems. Current academic research in transitions only pays attention to the changes in technologies in a single sub-system while industrial and policy documents call for whole system analysis of the sector. However, there is comparatively little research adopting a whole system analysis of GB's electricity sector which does not neglect the role of actors (McMeekin *et al.*, 2019). This study will address this gap in knowledge (***research gap 2***) and explore transitions of the whole sector to futures.

Within studies about electricity sector futures, researching energy flexibility is not a common practice (IEA, 2008). However, there was a significant increase in research on energy flexibility in GB following the trend in Europe. The first milestone was the open letter from Ofgem (2015b) to facilitate the use of new sources of energy flexibility in GB's electricity sector. Since then, many reports have been conducted featuring the benefits of energy flexibility, not only for the electricity system, but also for consumers and the wider society. However, these reports mainly focus on the technological aspects or policy implications of energy flexibility, while how transitions to new sources of energy flexibility may be achieved has received less attention. This study therefore looks at this gap in knowledge (***research gap 3***). This study will investigate transitions to low carbon futures and new sources of energy flexibility in GB's electricity sector.

The MLP is the most widely used analytical framework for studying transitions of the electricity sector. There is a considerable amount of empirical research has been conducted using the MLP, most recently analysing the transitions of the whole GB's electricity sector (McMeekin *et al.*, 2019). Moreover, the MLP has started to be used in policy research (Victor *et al.*, 2019; Geels *et al.*, 2019; Rogge *et al.*, 2020). In addition, it can open a space for emphasising the role of actors in transitions (Geels, 2004; 2011; 2020). Therefore, the concepts from the MLP are useful to study different low carbon energy futures, which focus on the role of actors and actor constituencies.

Understanding the underlying ontologies and epistemologies of the MLP is important because they impact how knowledge about futures of the sector is understood. The MLP is rooted in some theoretical foundations on socio-technical transitions including Social Construction of Technology (SCOT), evolutionary economics and neo-institutional theory (Geels, 2020). The MLP is not a theory of everything (ibid) but a middle range theory which can make crossovers with interpretivism/ constructionism and structuralism (Geels, 2010). "*Future*" is produced through the interactions of human actors arguing and defining the futures of the sector in particular ways. In other words, futures are socially constructed. Moreover, actors' capacities to act (i.e. agency) are guided by rules (Geels, 2004) or deep structures (i.e. discourses).

Although concepts of transitions research, in particular the MLP, are useful in this study, conventionally they are used to explore the development of a radical innovation in generation or consumption subsystems (e.g. Kern *et al.*, 2014; Smith *et al.*, 2014; Geels *et al.*, 2016). As such, the conventional approach of the MLP seems to be insufficient and fails to explore the transitions of the sector as a whole, especially the interactions of the variety of actors in GB's electricity sector, spanning across all sub-systems comprising the sector: generation, distribution and consumption. GB's electricity sector is experiencing multiple innovations rather than a single niche innovation. Transitions to futures of the sector require the development of innovations which fundamentally changes the logic of system linkages (i.e. architectural innovation) (McMeekin *et al.*, 2019). Here, the literature on architectural innovation appears to be a useful approach to understand the changes in system linkages which brings about transitions of the whole sector.

To explore how transitions come about, considering the role of power is important. As noted above, actors do not have equal power. Indeed, the conceptualisation of power is itself contested among transition scholars (Cashmore, 2018). Power is dominantly conceptualised as power of actors in transitions research (Avelino and Rotmans, 2009). However, by conceptualising power as power of actors without relating the notion of power to the structure of the system, i.e. system architecture, transitions research may fail to understand the whole system transitions of GB's electricity sector. Transitions involve not only agency but also agency in the relationship with other actors and structure (Geels, 2020). It is relevant to consider power as a productive force which emerges from both the interactions of actors and interactions between actors and structure. Here, the notion of power is useful in contributing to enrich the understanding of the whole system.

Power is a question of the representation expressed as discourses (Hajer, 1995). Some scholars have already used discourse approach to enrich their analysis of transitions (Walker and Cook, 2009; Scrase and Ockwell, 2010; Geels and Verhees, 2011). Discourses focus on collective meaning and sense-making of actors around specific issues (Geels and Verhees, 2011). Discourses also contain deep structural elements which are framed by actors (Geels, 2010). Discursive approach to transition; hence, also emphasised the interactions of structure and actors. Discourse "*enables those who subscribe to it to interpret bits of information and put them together into coherent stories or accounts*" (Dryzek, 1997, p.8). Stories can be a device for actors to express their interests and to be positioned (Hajer, 1995). Recognising the diversity of positions, discourse coalition, understood as a "*group of actors who share a social construct*" (Hajer, 1993, p.43) offer insights. Within a coalition, actors may hold different arguments but have a similar way of conceptualising the world (ibid), i.e. assumptions about the transitions of the sector. The notion of discourse coalition can help capture the mess emerging from the interactions of actors in transitions to low carbon futures and energy flexibility.

Based on three gaps in knowledge identified above and the research approaches to address these gaps, the following research aim and objectives which has been stated in Chapter 1 are articulated.

2.5.2 Aims

To critically investigate whole system transitions to low carbon futures and new sources of energy flexibility in GB's electricity sector.

2.5.3 Objectives

As identified above, future pathways and socio-technical scenarios in literature are largely *tidy* and fail to capture the messiness of futures emerging from the interactions of actors. Discourse coalitions are useful in capturing this messiness as each discourse coalition comprises of actors with different interests. Here, the first objective is:

- To identify dominant energy discourse coalitions within GB's electricity sector.

These discourse coalitions inform futures of the sector while futures play a key role in transitions. Hence, the second objective is:

- To identify futures of GB's electricity sector, focussing on the whole system analysis.

Within these futures of GB's electricity sector, transitions to new sources of energy flexibility need to be understood. Therefore, the third objective is:

- To identify how transitions to new sources of energy flexibility may be achieved in each future.

The following section sets out some analytical frameworks to meet these aims and objectives.

2.6 ANALYTICAL FRAMEWORKS

As argued in section 2.4.4, analysis of transitions can be enriched by discourses and discourse coalitions. This section identifies the discourse analysis framework and some contemporary energy discourses which will be used subsequently to analyse data in order to achieve the research aim and objectives. These discourses could shape transitions of GB's electricity sector to low carbon futures. Hence, this section forms a key part of the start of the '*progressive funnel*' (see section 3.2.3 for the details of this progressive funnel).

2.6.1 Discourse analytical framework

The concept of discourse analysis is contested because there are many "*versions*" or "*at least 57 varieties*" of discourse analysis (Van Dijk, 2003; Gill, 2000, p.173). Among them, there are two well-known approaches to discourse analysis which are Critical Discourse Analysis (non-Foucauldian perspective) and Foucauldian approach (Feindt and Oels, 2005).

Critical Discourse Analysis (CDA) focuses on languages and texts. Some key authors advocating this type of discourse analysis are Fairclough, Wodak, Van Dijk (Fairclough, 1992; 2003; Wodak and Meyer, 2009; Fairclough and Wodak, 1997; Van Dijk, 2005; Parker, 1992). Rooted in linguistics, it plays an important role in social sciences (Given, 2008; Breeze, 2011). Text, through meaning-making, can bring about changes (Fairclough, 2003). CDA refers to the analysis of texts in order to identify their processes of meaning making, which may cause social changes. According to CDA, once a social world is textually constructed, it becomes reality and limits the textual construction of the social world. Here, CDA follows realist point of view while as argued in section 2.4.1.4, realism does not provide much insights into transitions research. Therefore, CDA is not useful in this study.

In contrast, Foucauldian discourse analysis concentrates on knowledge and the relationship of knowledge and power rather than language itself (Feindt and Oels, 2005). According to Foucaudian approach, a discourse is "*constitutive of reality in that it physically shapes reality*", i.e. is constructed through "*being engaged with the world and of being related to it*" (Ibid, pp.165). Power relations are present in these social engagement/interactions and as a productive force (ibid). Seen in this way, Foucauldian discourse analysis has a constructionist ontology in accord with the ontological root of the MLP (section 2.4.1.4) and the conceptualisation of power (section 2.4.3). Hence, Foucauldian discourse analysis is chosen for this study.

Drawing on a Foucauldian approach to discourse, Dryzek (1997) and Hajer (1995) offer useful analytical frameworks and concepts to analyse discourses to transitions.

Dryzek (1997) developed a framework with four elements to analyse several contemporary environmental discourses (Table 2.3). These elements are:

- Basic entities: Discourse recognises the existence of different elements.
- Assumptions about natural relationships: Each discourse not only recognises the existence of basic entities but also the relationships between these basic entities.
- Agents and their motives: Each discourse not only recognises of "things" and relationships of "things" but also human. Things and human can have power and agency which are assumed in each discourse.
- Key metaphors and other rhetorical devices: Discourse uses languages including metaphors or other rhetorical devices to convince listeners or readers.

This environmental discourse analytical framework is useful in analysing electricity/energy discourses because decarbonisation is driving electricity debates as reviewed in section 2.2.2. In

Table 2.3: Environmental discourses analytical framework (Dryzek, 1997)

1.	Basic entities
2.	Assumptions about natural relationships
3.	Agents and their motives
4.	Key metaphors and other rhetorical devices

order to meet research objectives 2 and 3, the four elements of this analytical framework are adapted to develop an energy discourse analytical framework (Table 2.4), as follows:

- The first two elements '*basic entities'* and '*assumptions about natural relationships'* are changed to '*system components'* and *'system relationships'* in order to address the whole system analysis in **research objective 2**. A whole system transition of GB's electricity sector is considered as changing in not only socio-technical system components but also in the architecture of the system, i.e. system relationships. Here, system components comprise of any technologies, innovations, infrastructures, institutions or actors in futures following the visions of interviewees. System relationships focus on the linkages between system components.

- The third element '*agents and their motives'* is changed to '*power'* to understand the conceptualisation of power in whole system transitions and assist in **meeting research objective 2**.
- The last element about *key metaphors* only focuses on *the metaphor of energy flexibility* to understand how transitions may unfold according to interviewees' vision and **to meet research objective 3**.

Dryzek's analytical approach to discourse analysis (Table 2.3) using four elements (*basic entities, assumptions about the natural relationships, agents and their motives, and key metaphors*) was translated into a new and more appropriate approach for this study (Table 2.4) and used subsequently in Chapter 5. The four translated elements in this new approach are *system components, system relationships, power, and the metaphor of energy flexibility*.

This translation was needed because although the Dryzek's approach was found useful (as explained above), it is too '*broad brushed*' to investigate developments in GB's electricity sector. The translation was also needed to ensure that the research aim and objectives identified in sections 2.5.2 and 2.5.3 were achieved and specifically, enabled analysis of "*the whole system*", consisting of both components and their relationships.

In order to **meet research objective 1**, Hajer's (1995) Argumentative Discourse Analysis which focus on discourse coalitions as analytical concepts is useful (also see section 2.4.4.2). The following sections look at some contemporary energy discourses which are dominant in energy sector now.

Table 2.4: Energy discourse analytical framework – adapted from Dryzek (1997)

1.	System components
2.	System relationships
3.	Power
4.	The metaphor of energy flexibility

2.6.2 Contemporary energy discourses

A discourse coalition can be considered to be dominant when it fulfils two requirements (1) Discourse structuration and (2) Discourse institutionalisation. Discourse structuration "*occurs when a discourse starts to dominate the way a society conceptualises the world*" (Hajer, 1993, p.46). Discourse institutionalisation occurs when a discourse "*solidifies into an institution, sometimes as organisational practices, sometimes as traditional ways of reasoning*" (ibid). For example, Leipprand et al (2017) considered energy transition as a discourse coalition on Germany energy future which is structuralised and institutionalised in German parliament.

Firstly, this section is based on some contemporary environmental discourses from Dryzek (1997). Complete discontinuity of these environmental discourses is rare (Dryzek, 1997). Three of them (1) economic rationalism, (2) administrative rationalism and (3) ecological modernisation are dominating discourses in the energy sector as arguing below. Secondly, this section reviews two other recent contemporary discourses which are (4) consumer sovereignty and (5) energy democracy. These five discourses can potentially become dominant energy discourse coalitions because they all fulfil two conditions of discourse structuration and discourse institutionalisation as summarised in Table 2.5. These five discourses are looked at in turn below, following Dryzek's (1997) analytical framework (Table 2.3) mentioned in section 2.6.1. These discourses are then used as a baseline to identify dominant energy discourse coalitions in Chapter 4, i.e. to group actors into discourse coalitions.

2.6.2.1 Economic rationalism

Economic rationalism advocates the role of a market where a market mechanism is intelligently deployed to achieve public ends (Dryzek, 1997, p.102). In economic rationalism, market and prices are basic entities. This discourse assumes that the basic relationship between actors (individual and collective) is competitive. Actors in economic rationalism hence are motivated by *material self-interest, and pursuing it rationally*" (Dryzek, 1997, p.113). In other words, actors act economic

Table 2.5: Potential dominant energy discourse coalitions from literature

Discourses/ Conditions	Discourse structuration (in GB's electricity sector)	Discourse institutionalisation (in GB's electricity sector)
Economic rationalism	Has dominated since 1990s	Electricity privatisation
Administrative rationalism	Most recently	Net Zero target
Ecological modernisation	Has dominated since Stern review (2007)	The Clean Growth Strategy (2017)
Consumerism	Most recently	In energy economic community (2018)
Energy democratisation	Most recently	Trade Union, non-governmental organisations, think tanks and policy groups

rationally. The metaphors mainly used in this discourse is "*free*" which implies a free market with less government intervention.

Economic rationalism has been introduced into the energy sector since liberalisation. The liberalisation of GB's electricity sector started in 1990s with the privatisation of power plants and electricity grids (Everett *et al.*, 2012). The task of liberalisation "*was largely to get the government out of the way, and stamp out all residual traces of the old planned CEGB world*" (Helm, 2014). The free (laissez faire) market approach advocates the freedom of contracting in electricity market (Helm, 2014). Economic rationalism discourse was developed in contrast with a "*market discourse with regulation*". Market regulation, in the electricity sector (Ofgem), beginning when Margaret Thatcher became Prime Minster in 1979, is "*subject to public power*" i.e. regulation represents the power of the public sector (Mitchell, 2008, p.26). As a consequence, "*top down micro-management continued*" (ibid) and constrained the development of the free (laissez faire) market in the energy sector. Economic rationalism as such does not fully gain discourse institutionalisation, i.e. regulation always presented in the electricity sector. Hence, in this case, economic rationalism discourse is based on the belief that the market with lighter government intervention (rather than without government intervention) can deliver the best outcome.

2.6.2.2 Administrative rationalism

Administrative rationalism is defined as "*the problem-solving discourse which emphasises the role of experts rather than citizen or producer/consumers in social problem solving, and which stresses social relationships of hierarchy rather than equality or competition*" (Dryzek, 1997, p.63). The basic entities in this discourse are administrative state (government), experts and managers. They are the one who are subordinated. Governing is about "*rational management in the service of a clearly-defined public interest, informed by the best available expertise*" (Dryzek, 1997, p.74). It means that the final decision is in the hand of the government who acts rationally. Governmental policy is informed by experts with their cost-analysis and risk-analysis. Governments, experts and managers are all motivated by public interests. These public interests reflect the "*administrative mind*" of those following this discourse.

This discourse has dominated decision making of the UK government in variety of areas including environment, public health, energy and so on. Since the 1960s, solutions for environmental issues are associated with public policy which traditionally is based on scientific expertise (ibid). For example, in the current COVID-19 outbreak, governmental public policy and decision are based on variety of research and recommendations from science and health experts.

Recent publications have recognised this approach in energy policy. For example, BEIS in combination with Ofgem has consulted actors in energy sector about the need to have a smart and flexible system in a call for evidence document (2016) before designing a plan (2017). Most recently, in June 2019, the UK committed to Net Zero carbon emission (BEIS, 2019b) after receiving recommendations with evidence from Committee on Climate Change (2019) in May.

2.6.2.3 Ecological modernisation

Ecologic modernisation is defined as "*a restructuring of the capitalist political economy along more environmentally sound lines*" (Dryzek, 1997, p.141). Basic entities in this discourse are complex system with things and actors such as capitalist economy or the state. Hence, this discourse embraces the relationship between them, especially *"environmental protection and economic prosperity go together*" (Dryzek, 1997, p.146). Here, actors are motivated by public goods e.g. environmental protection. The word "*modernisation*" of this discourse means "*development*" which implies progress of both environment and economic development. This is the discourse of reassurance.

Ecological modernisation was identified in 1980s (Ibid). Ecological modernisation is more recognised in GB's electricity sector after Stern Review: The Economics of Climate Change (Stern, 2007). This review emphasised the collaboration in economic growth and environmental degradation. This perspective is given a national push from the governmental Clean Growth Strategy (BEIS, 2017).

This discourse recognises that the uncertainty of scientific reports should not be used to delay environmental actions. This view is at odds with administrative rationalism which advocates the certainty of scientific reports.

2.6.2.4 Consumer sovereignty

The consumer sovereignty discourse in the energy sector has become very popular. It takes into account social interactions of consumers with the industry. Consumer culture or consumerism is emphasised and consumers' identities are formed by the way they consume products and services (Urry, 2016). Manufacturing of products should therefore be based on consumers' preferences (Hutt, 1943; Menges, 2003). Consumer sovereignty "*rests on the reasonable premise that economic activities must ultimately be aimed at satisfying consumers"* (Gordon and Olson, 2000, p.2). Here, this discourse emphasises the relationship between consumers and the industry.

Since the 1990s, the development of Internet and Information and Communication technology (ICT) brings about different experiences for consumers. For example, E-business model such as E-bay seemingly departed from existing business models by providing free services to consumers (Boons *et al.*, 2013). Also during this time, GB's electricity sector was privatised and operated under the regulator – Ofgem whose first remit is to protect the interest of consumers. However, the focus on consumers has not been emphasised until recently. Consumers are now expected to contribute significantly to the transitions of the sector through the development of some provisions which might need the engagement of consumers such as energy flexibility or the concern that consumers might be left behind (Sustainability First, 2019). Consumer sovereignty emerges and places consumers at the heart of the energy system. For example, actors in the energy sector embraced consumer sovereignty and discussed "*Consumers at the Heart of the Energy system?*" in a research conference with the attendance of government, industrial actors, energy analysts and so on (British Institute of Energy Economics, 2018).

2.6.2.5 Energy democracy – the last "D" of the 4Ds

As identified in section 2.2.2.5, energy democratisation is one of the elements of the 4Ds used to describe the current changes of GB's electricity sector. Energy democratisation is added to the original 3Ds (Decarbonisation – Decentralisation and Digitisation) with the involvement of consumers in generating electricity. Also paying attention to consumers and their agency in the future, energy democracy is another dominant discourse in energy field. This discourse reflects the move from fossil fuel to renewables and from large companies to prosumers. Prosumers are empowered and have power in this discourse. This also means that energy democracy supports decentralisation of decision making.

In summary, this chapter reviewed literatures focussing on ensuring electricity security of supply to the development of GB's electricity sector with the changes/ transitions to low carbon future and new sources of energy flexibility. Several key gaps in knowledge were identified and research approaches to address these gaps were explored, leading to formulation of research aim and objectives. Finally, analytical frameworks with some dominant energy discourses to be used in data analysis were set out.

CHAPTER 3 METHODS

3.1 INTRODUCTION

The findings of the literature review were presented in the previous chapter. A number of gaps in knowledge were identified and the research aim and objectives of the study were set out to address these. This chapter focuses on the methods selected and adopted to meet these aim and objectives. Following a number of authors such as Robson and McCartan (2016), Marshall and Rossman (2016), Bryman and Bell (2011), this chapter firstly identifies the selection of a flexible design. Other selections for key aspects within this flexible design included (1) research purposes, (2) research ontology, (3) theories or conceptual frameworks, (4) research strategy, (5) type of data collected, (6) data-collection techniques, (7) sampling strategy, and (8) data analysis techniques. Research quality and research ethics are also discussed below.

3.2 RESEARCH DESIGN

Research design is an essential part of a research project (Robson and McCartan, 2016) because it "*deals with aims, purposes, intentions and plans within the practical constraints of location, time, money and availability of staff*" (Hakim, 2000).

In real world research, there are three major types of research design (1) fixed design, (2) flexible design and (3) multi strategy design which is a combination of fixed and flexible design. A fixed design requires a "*tight pre-specification*" before coming to the main stage of data collection (Robson and McCartan, 2016, p.75). This design refers to a one-way process of articulating aim and objectives and choosing methods to meet these aim and objectives. For example, research purposes and a conceptual framework help the researcher to develop research questions or identify research aim and objectives. When the researcher identifies the aim of the research, he/she can decide which methods and sampling strategy are appropriate. As such, fixed design is theory-driven (*ibid.* p.101). In other words, the researcher must have a "*substantial amount of conceptual understanding*" about a phenomenon which he/she is studying and a "*clear idea*" of what he/she needs to do. The research using this design usually concentrates on the outcomes. Moreover, this research design is appropriate with descriptive or explanatory studies and usually adopts experimental or non-experimental studies. Additionally, fixed design is often considered as a quantitative design because data are usually in the forms of numbers (Robson and McCartan, 2016, p.75).

A flexible design has some contrasting characteristics with a fixed design (see Figure 3.1). A flexible design emerges during data collection and represents a two-way relationship between the components. As the research project progresses, all the components of the research design need to be revisited. With a flexible design, the researcher may not have a clear idea of "*which theoretical framework is going to be the most helpful*" (Robson and McCartan, 2016, pp.76 and 146). This design often focuses on processes and is suitable for a descriptive and exploratory study. The main strategies used in this design are case studies, ethnography and grounded theory studies. Data in this design is usually in the form of words; hence, this design is often referred to as a qualitative strategy. Table 3.1 summarises the key features of fixed and flexible research design.

Flexible design was selected for this study as it gives the researcher the flexibility to revisit every component of the research design during the studies. Flexible design is also appropriate because the theoretical framework to study futures of an electricity sector is not fully developed. The Multi-level Perspective, which is rooted in among others, Giddens's (1984) structuration theory, is initially chosen to guide the research. However, there was not a definitive, fixed idea at the beginning of the research whether MLP theory would work. The process of how the researcher identifies the conceptual framework is described in section 3.2.3. Another reason for the suitability of a flexible

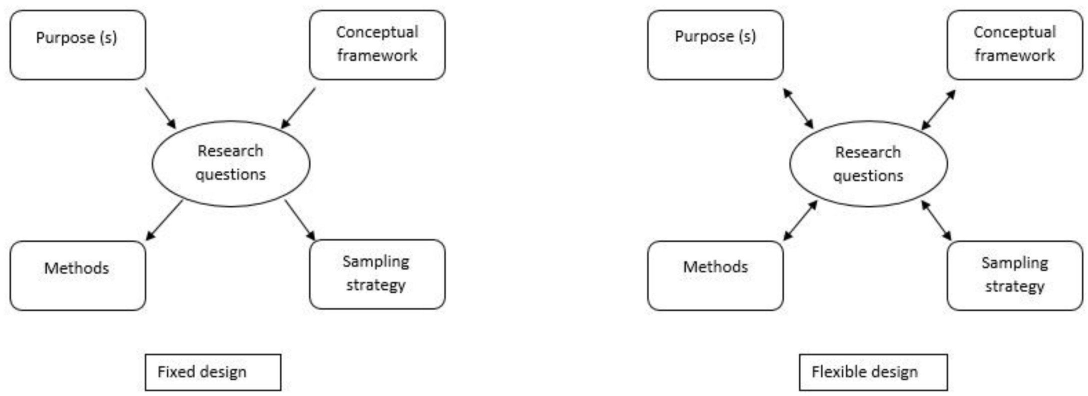


Figure 3.1: Framework for research design - adapted from Robson and McCartan (2016)

Table 3.1: Fixed design vs Flexible design - adapted from Robson and McCartan (2016)

	Fixed design	Flexible design
Main features	Components are fixed	Components can be revisited
Theoretical framework	Is developed from the outset	Is under-developed at the outset
Focus on	Outcomes	Processes
Research purposes	Descriptive or explanatory	Exploratory and descriptive
Research strategy	Experimental or non-experimental strategy	Case-studies; ethnography or grounded theory
Type of data collected	Quantitative data in numerous form	Qualitative data usually in the form of words

design is that this study does not only concentrate on the futures, but on transitions (the processes of the changes) to futures of GB's electricity sector. In other words, the study looks at how futures are constructed and how transitions to a low carbon future come about, which involve the process of changing from one socio-technical system to a more sustainable socio-technical system (Geels, 2011) which is a low carbon system in this study. The following sections describe and justify the research purposes, research strategy and type of data collected within the chosen flexible research design.

3.2.1 Research purposes

There are three common research purposes: (1) Explanatory, (2) Descriptive and (3) Exploratory (Robson and McCartan, 2016; Marshall and Rossman, 2016). Explanatory research "*seeks*" to provide explanation for or to understand a situation which focus on causal relationships, i.e. shows relationship between events (Marshall and Rossman, 2016). Descriptive research provides a clear description of a characteristic of something. Exploratory research focuses on a poorly understood situation by exploring what is happening in this situation (Robson and McCartan, 2016). This study does not explain why transitions occur in the sector or describe these transitions. Rather, the purpose of this study is exploratory because transitions to low carbon futures and new sources of energy flexibility in GB's electricity sector contain uncertainty and are poorly understood. This study hence will focus on exploring how such transitions come about.

Before looking at the chosen conceptual framework, the next section sets out the research ontology and epistemology and *logics of enquiry*. The importance of these concepts in the choice of conceptual frameworks selected to meet the aim and objectives is also discussed.

3.2.2 Research ontology and epistemology

Research ontology and epistemology relate to different views of the world and knowledge underpinning research aim and objectives. Ontologies and epistemologies underpinning research transitions (the MLP) have been identified in section 2.4.1.4. This section considers ontologies and epistemologies of this study.

There is not a single definition of knowledge. "*What knowledge is*" depends on "*the questions that you are asking*" and "*your standpoint from which you are asking*" (Stainton-Rogers, 2006). Hence before making a "*significant contribution to knowledge*", there is a need to explicate the assumptions that lie behind the choices of research questions and conceptual frameworks. These assumptions include ontological assumptions about the "*nature of the world*" (Ibid). Positivist ontology considers the world as an objective, totally separate from human meaning-making (Ibid). On the other hand, constructionist ontology sees the world subjectively as humans make sense of the world through their activities (Ibid). Respectively, there are two main types of epistemology (1) positivist and (2) constructionist. Epistemology is the "*study of the nature of knowledge*" (Ibid). It concerns about what is acceptable knowledge in a field (Bryman and Bell, 2011, p.15). A positivist approach gains knowledge through observing the world in an objective manner (Stainton-Rogers, 2006). In contrast, a constructionist approach sees the world in the relationship with humans. Constructionists hold to three principles (1) knowledge is constructed rather than discovered, (2) knowledge has multiple rather than singular meanings and (3) knowledge is a means by which power is exercised (Stainton-Rogers, 2006). Table 3.2 compares three types of epistemology, inspired from Robson and McCartan (2016), Stainton-Rogers (2006), Bryman and Bell (2011).

In between these two main ontological approaches, realism lends itself well to real world research. However, it is not relevant to follow realism in this study. It recognises both the natural and physical world as well as the social world (Robson and McCartan, 2016). It pays attention to the social reality and purports that knowledge is both constructed and based on the social reality. It is a pragmatic approach focussed on theory building to explain the real world (Ibid) and thus used in explanatory research. As this study is exploratory and does not focus on theory building, this study is not founded from realism. The following arguments provide justification of a constructionist perspective in this study.

The constructionist ontology and epistemology is appropriate in this study for a number of reasons. First, constructionist ontology and epistemology allows for findings that can be surprising (Bryman and Bell, 2011) or represent many uncertainties (Valentine *et al.*, 2017). This study explores transitions of GB's electricity sector to futures which are uncertain. As noted in section 2.3.1.2.3, these transitions are uncertain because involve different actors' interactions and non-linear nature of innovations. There is considerable uncertainty in the nature and content of the transition process and future.

Second, constructionism considers "categories" which people use to help them understand the world. These are "*social products*" through which meanings are constructed from interactions of human actors, rather than being "*pre-given*" (Bryman and Bell, 2011, p.22). These categories can be an organisation, a culture or a future. For example, a "*future of GB's electricity sector*" is a social product because meanings of "*future*" are produced through the interactions of human actors in the sector arguing and defining the futures of the sector in particular ways. In other words, futures are socially constructed.

Table 3.2: Positivism, critical realism and constructionism - adapted from Robson and McCartan (2016), Stainton-Rogers (2006), Bryman and Bell (2011)

Positivism	Realism	Constructionism
Follows natural science such as physics, chemistry, biology	Follows both natural and social science	Follows social science which focus on researching human beings in social situation. Social science focus on human language and interactions between people in social situations.
Human is not an object of research but is the objects of natural world	Human is an object of research. Human beings are purposive actors who have ideas about the world and attach meanings around what happens. Human act rationally	Human is an object of research. Human beings are purposive actors who have ideas about the world and attach meanings around what happens.
Facts are the truth and can be observed. Scientists looking at the same bit of reality see the same thing. Main task of doing research is to observe	Facts are theory-laden. Main task of doing research is to invent theories to explain the real world.	Facts are meaningful story telling. Main task of doing research is to interpret and understand the social constructions of meaning and knowledge
The researchers see human behaviours from his/her point of view	The researchers see human behaviours from that person's point of view and seeks to theorise human behaviours.	Human behaviours depend mainly on their belief and meanings they attach to action. The researchers see human behaviours from that person's point of view
Knowledge is an object which does not relate to social actors	Knowledge is both constructed and based on the social reality	Knowledge is social constructed from the perceptions and actions of social actors.
Social phenomena and their meanings are external facts that are beyond our reach or influence	Mechanisms and structures producing phenomena and events are concerned than phenomena and events themselves	Social phenomena and their meanings are socially constructed by human actors as they interact and engage in interpretation.
Organisations have rules, regulations and cultures which constraint the ways that their employees act.	The ways that rules, regulation and cultures constraining the ways that organisational employees act are concerned.	Rules, regulations and cultures of organisations are not too command, but much more like general understandings. Employees' share understandings can form such rules, regulations and cultures.
Follow quantitative paradigm and deductive logics of enquiry	Follow both quantitative paradigm and qualitative paradigm, follow inductive and abductive logics of enquiry.	Follow qualitative paradigm; and inductive and abductive logics of enquiry

Third, according to constructionism, "*those who create knowledge*" will "*gain power*" (Stainton-Rogers, 2006). Seen in this way, knowledge is considered as a means through which power is exercised. In this study, actors in the sector use discourses to attach meanings to futures, create legitimate knowledge to these futures and gain power. As such, knowledgeable actors exercise power of discourses to shape futures of the sector. Hence, this study adopts a constructionist approach.

Finally, a constructionist approach underpins and conforms to the flexible design with qualitative methods chosen in previous sections (Robson and McCartan, 2016; Bryman and Bell, 2011). The flexible design is useful in situations where theory is underdeveloped and provides little guidance for the researcher as mentioned at the beginning of Section 3.2. The role of theory and conceptual frameworks in flexible design is discussed in the next section.

3.2.3 The role of theory in flexible design

This section looks at what theory is, the role of theory in research, the chosen logics of enquiry and the research process as a "*progressive funnel*" which becomes more focussed during the course of this study. The end of this section describes reflexivity as an important element in research.

Theory is "*an explanation of what is going on in the situation, phenomenon or whatever we are investigating*" (Robson and McCartan, 2016, p.66). Theory helps researchers to understand about the world because it not only provides a framework to "*critically understand phenomena*" but also supports the consideration of how the unknown might be organised (Silverman and Marvasti, 2008, p.133). Given the importance of theory in real world research, Bryman and Bell (2011) consider two issues for linking theory with research: (1) there is a matter of what type of theory that researcher should use and (2) whether data are collected to test or to build theories.

Firstly, there are two types of theory: (1) grand theories such as structuration theory of Giddens (1984) which operate at a more abstract and general level and (2) middle-range theories such as the MLP which operate at a more empirical level. Merton (1967) argued that the abstract nature of grand theories are not useful in guiding researchers how they can find empirical evidence. In contrast, Bryman and Bell (2011) gave an example from Bresnen et al (2004) to prove the usefulness of grand theory, using Giddens's (1984) structuration theory to understand the influence of the interplay between structure and agency on diffusion and enactment of managerial knowledge. Besides, middle-range theories only represent a limited aspect of social life although it brings the researcher near to empirical research. Overall, theory means "*little more than the background literature in an area of social enquiry"* (Bryman and Bell, 2011, p.10).

Secondly, there are two contrasting perspectives about the role of theory in research: (1) research questions are theoretically informed (Silverman and Marvasti, 2008, p.141) and (2) theories are sought after data collection and analysis. These two perspectives reflect two common approaches to logics of enquiry which are (1) deductive and (2) inductive, respectively. The researcher with deductive logic develops hypothesis from a theory, then collect and analyse data to test this theory (Stainton-Rogers, 2006; Bryman and Bell, 2011; Robson and McCartan, 2016). Conversely, induction draws interferences from observations to make generalisation and to build theory (Stainton-Rogers, 2006; Bryman and Bell, 2011; Robson and McCartan, 2016). Deductive logic is normally used in quantitative approach while inductive logic is usually used in qualitative approach.

Deduction and induction logics of enquiry are popular in social research but they are not appropriate to use in this study. First, deductive logic is a linear process while research about futures contains uncertainty and the researcher may not know if the data set is relevant to use before data collection phase (Bryman and Bell, 2011). The linear process of such logic does not allow the researcher to alter the chosen theory to fit within the research, hence, does not fit with "real world" research and flexible design (Robson and McCartan, 2016). In terms of inductive logic, although it is useful in qualitative approach, it is not suitable for transitions research because the transition of the whole sector is a complex process involving many aspects, organisations and people which requires guidance from a theory to manage properly. In this study, concepts from some established frameworks or theories in transitions research including the MLP, architectural innovation, power and discourses are argued to be useful (see section 2.4.1). More importantly, both deductive and inductive logics usually share the approach of "*reductionism*" when dealing with complexity and are associated with positivism (Stainton-Rogers, 2006, p.84). As such, they do not fit the constructionist ontology of this study.

Abductive logic of enquiry fits with the exploratory purpose of this study although it is a much less familiar term than deduction and induction (Stainton-Rogers, 2006). Abduction contains theory construction to gain insights and understandings on how the world operates, rather than theory testing (deductive) or theory building (inductive) (Ibid). It identifies and creates naturally occurring surprises (Stainton-Rogers, 2006). With the complexity of research of futures and transitions, this logic seeks to unfold the unexplained phenomena of the transitions of GB's electricity sector to futures by focusing on "*the unexplained*" rather than "*trying to get round complexity by fitting phenomena in an existing theoretical framework*" (Stainton-Rogers, 2006, p.85). Furthermore, with abduction logic, research questions are theoretically informed (Dubois and Gadde, 2002; Stainton-Rogers, 2006) but research hypotheses are not formally set (Shank, 1998), which allows the researcher to modify research theory and questions if needed. This feature of an abductive logic of enquiry is in line with the chosen flexible design. This logic of enquiry also conforms to constructivist approach (Bryman and Bell, 2011). An abductive logic of enquiry is therefore also used in planning for the study. It helps the researcher to gain insights into the complexity of a changing electricity sector as it adapts to accommodate more low carbon technologies and develops new sources of flexibility.

As the purpose of this study is to explore and gain insights on how the world operates (abductive), the concept of "*progressive funnel*" of Hammersley and Atkinson (2007) and Marshall and Rossman (2016) is useful in this study. As a funnel, the research is being "*progressively focused over its course*" (Hammersley and Atkinson, 2007, p.160). This progressive funnel is illustrated in Figure 3.2. The funnel starts when the gaps in knowledge from are identified in literature. As shown in Chapter

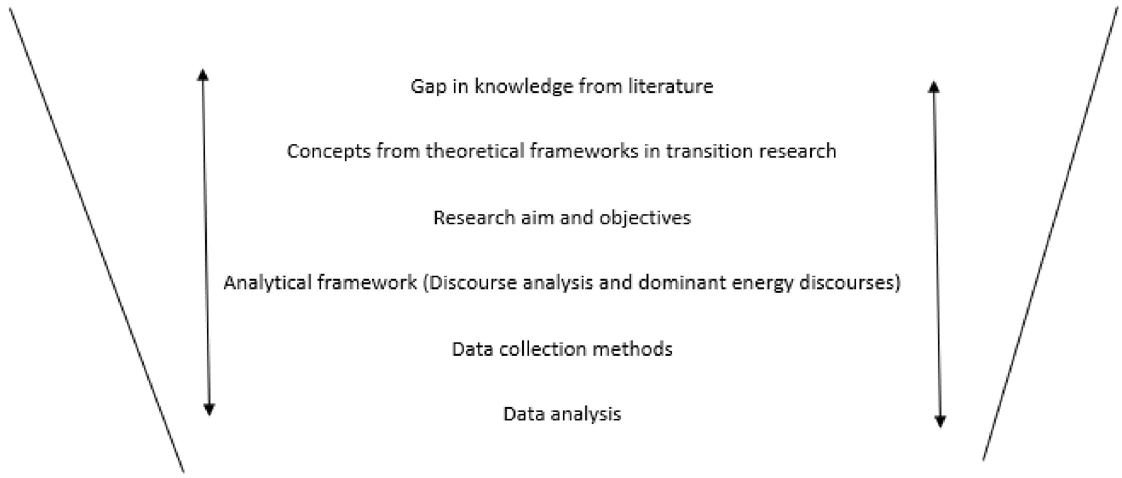


Figure 3.2: An illustration of the research process as a progressive funnel of this study

2, these gaps in knowledge are whole system analysis of transitions of GB's electricity sector and new sources of energy flexibility to low carbon futures which are quite broad initially. In order to address these gaps, the concepts and ideas of some general theoretical frameworks were found useful, including the MLP, architectural innovation, power and discourses in transitions research. These concepts instead of the theory were adopted in this study to guide data collection and analysis. As this study will become gradually focussed, the research aim and objectives were identified. After that, the analytical framework of discourse analysis following Dryzek (1997) and some contemporary dominant energy discourses were identified from literature. These analytical framework and energy discourses are then used subsequently in data analysis.

This "*progressive funnel*" follows an iterative process where the tasks of reviewing literature, collecting data and analysing data are intertwined and gradually refined during the process of the study. The insights from literature informs data collection and analysis. Subsequently, new insights from data collection and analysis stimulates further literature review, data collection and analysis. As such, this funnel can be used to demonstrate the process of unfolding the transitions of GB's electricity sector. The objectives of the study are also refined along this iterative process through data collection and analysis in light of the theoretical framework. This iterative process is ongoing until this study is completed. This study is completed when the aim and objectives are met. By conceptualising this study process as a funnel following iterative process, this study is relevant with flexible design identified above.

This "*progressive funnel*" also reflects a process of reflexivity of the researcher (Hammersley and Atkinson, 2007). Reflexivity "*acknowledge the central position of the researcher in the construction* *of knowledge*" (Finlay, 1998, p.1). Reflexivity plays an important role in research (Broadbent and Laughlin, 1997) and rejects the idea that social research and its findings can be unaffected by "*the biography of the researcher*", i.e. researcher's subjectivity (Hammersley and Atkinson, 2007, p.15). However, subjectivity does not mean bias. According to social constructionism, reality is socially constructed, and meanings are negotiated in particular contexts and subject to multiple subjective interpretations (Finlay, 1998). Here, reflexivity should be embraced which enable rich understandings of the research, rather than to dismiss it as bias (ibid). In this study, the researchers' subjective interpretation is not a problem because it was reflected by the "*progressive funnel*" or the process of gradually refining literature, data collection and data analysis. Data were collected and analysed in light of the literature (concepts from transitions research and analytical frameworks) and literature was further reviewed during the process of data collection and analysis.

Following the chosen research purposes and research funnel, research methods are considered. These methods consist of a research strategy, type of data collected and data collection techniques.

3.2.4 Research strategy

There are three widely used flexible design research strategies including: (1) ethnographic studies; (2) grounded theory studies; and (3) case study (Robson and McCartan, 2016, p.146). The main characteristics of these strategies are described and the justification for the selection of a case study is described below.

An ethnographic study focuses on a specific social group and normally involves observing the group in their natural environment over an extended period of time (Robson and McCartan, 2016). Conducting an ethnographic study means that the researcher needs to spend an appropriate length of time to observe a group in its natural environment in order to describe and interpret its culture and social structure. Ethnography has an advantage of generating "*thick descriptions*" (Geertz, 1973) of a group's culture and behaviour (Robson and McCartan, 2016). However, it requires the researcher to get involved in a cultural setting for "*two or more years*" (Robson and McCartan, 2016). This study requires the researcher to understand different perspectives of different actor groups; hence, it is not realistic for the researcher to conduct an ethnography study with many different groups within the PhD duration.

A grounded theory study focuses on developing a theory of a particular social situation forming the basis of the study. Although this study is grounded on the MLP, architectural innovation, discourse analysis and power literature, it does not seek to generate any theory. Thus, grounded theory studies are not suitable for the research.

Case study research is "*an intensive analysis of an individual unit (as a person or community) stressing developmental factors in relation to environment*" (Flyvberg, 2011, p.301). Similarly, case study is an "*empirical inquiry*" which is used to "*investigate a contemporary phenomenon in depth within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident*" (Yin, 2009, p.18). These two definitions of a case study strategy both agree that case study of a phenomenon is appropriate when it is impossible to separate the phenomenon from its context. In this study, energy flexibility and transitions of GB's electricity sector are both contemporary phenomena that need to be understood in depth in the context of GB's electricity sector. Moreover, case study research is concerned with "*complexity and particular nature of the case in question*" (Bryman and Bell, 2011, p.59) which is useful in investigating uncertain and messy futures. Using a case study is also consistent with this study's research purpose which is exploratory. Hence, the case study research strategy is selected.

Case study research is an established strategy used for studying transitions in electricity sectors. Geels et al (2016) and McMeekin et al (2019) used a case study of the UK (and Germany's electricity sector) to examine historical low carbon transitions. Foxon (2013) and Geels et al (2020) conducted several case studies to explore transition pathways to a GB low carbon future. Geels and Verhees (2011) and Rogge et al (2020) applied their research in a case study of the historical Dutch nuclear energy and of the future Germany electricity sector, respectively.

In practice, the researcher can choose to conduct a single case or multiple cases. Figure 3.3 shows different types of case study. A case can be a situation, an individual, an organisation, a group under its context (Robson and McCartan, 2016, p.149). Multiple cases are multiple situations, individuals, organisations, groups under many contexts such as different sectors in a country or different countries.

A case study with multiple cases has many advantages. A multiple case study strategy can be pursued to allow the researcher to compare and contrast cases and key findings(Bryman and Bell, 2011, p.63). However, a multiple case study approach is not relevant to this study because it "*tends to mean that the researcher pays less attention to the specific context and more to the ways in which the cases can be contrasted*" (Bryman and Bell, 2011, p.67).

A single case study is selected because it is relevant to the aim of this study which focus on transitions of the sector as a whole, i.e. whole system analysis. GB's electricity sector can be seen as a single system with elements providing societal functions including electricity generation, distribution and consumption, in other words: "*a bounded situation or system, an entity with a purpose and functioning parts*" (Bryman and Bell, 2011, p.60).

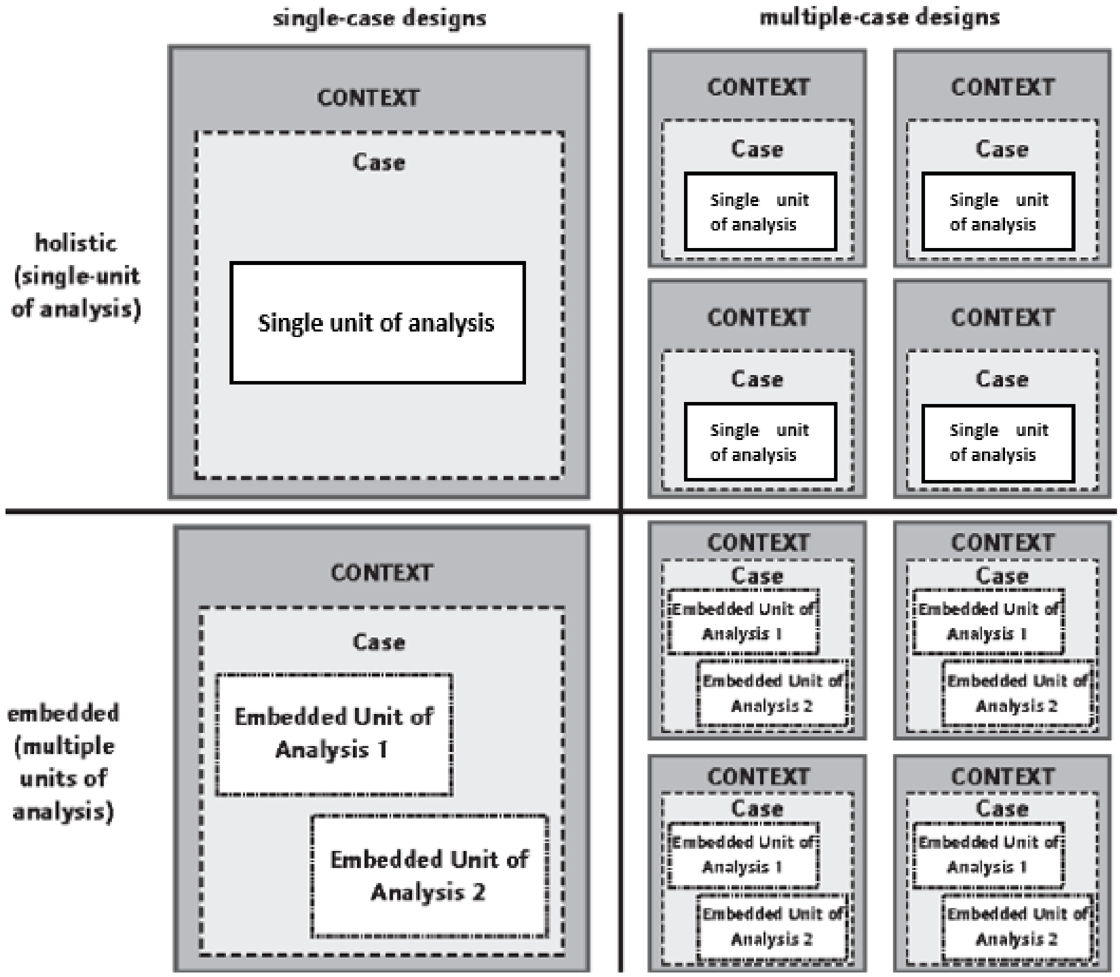


Figure 3.3: Different types of case study strategy (Yin, 2009, p.46)

Deciding on the unit of analysis' boundaries is the most important element of a case study strategy (Flyvberg, 2011). Single case study strategies are differentiated on the basis of the level of unit of analysis (Yin, 2009; Robson and McCartan, 2016). A study where the focus is on "*a single, global level*" is regarded as "*holistic*" (Robson and McCartan, 2016, p.153). The single case study provides singular unit of analysis which is the whole GB's electricity sector with the boundary spanning three main societal functions: generation, distribution (network) and consumption. Focussing on the whole or GB level of the electricity sector allows an understanding of the system level outcomes arising from the interrelationships between different components of the system. Using a holistic, single case study enables a focus on transitions as a whole, rather than sub-system transitions.

Although a holistic case study might be useful in this study, it raises a question of how it can be generalised. In other words, how the findings from only one single case study can be representative and apply generally (Bryman and Bell, 2011). Although some researchers claim the generalisation of a single case study (Bryman and Bell, 2011, p.61), this is consistent with a positivist approach which is not in line with this study (Flyvberg, 2011; Robson and McCartan, 2016). In qualitative research, generalisability does not mean "*the extent to which the findings of the enquiry are more generally applicable outside the specifics of the situation studied*" as in quantitative research (Robson and McCartan, 2016, p.78). Instead, the goal of a case study is more about developing a deep understanding of a research phenomenon (Bryman and Bell, 2011). Hence, the uniqueness of a case study is more important than its representativeness. In this study, transitions of GB's electricity sector are unique, but this does not represent other sectors in Britain or other electricity sectors in other countries. This issue is considered in more details in section 3.2.9 which discusses research quality. The type of data needed in such case study to meet the aim and objectives of the research is identified in the following section.

3.2.5 Type of data collected

There are three common types of data collected including 1) quantitative 2) some combination of quantitative and qualitative 3) qualitative. Collection of quantitative data or some combination of quantitative and qualitative data was not part of the research design for several reasons. First, quantitative data is normally collected in a fixed design research. Second, quantitative data is in numerical form, which is not appropriate to explore actors' visions and expectations about futures.

In contrast, as mentioned at the beginning of section 3.2, flexible design usually uses qualitative data. Moreover, qualitative data are generally linked with social constructionism (Robson and McCartan, 2016). Social constructionism argues that society does not exist separately from human actions but is constructed through the interactions between people. The language, form of words and discourses which arise provide "*thick descriptions*", which means rich accounts of the details of culture (Geertz, 1973). This type of qualitative data is relevant to this study where the description of different discourses needs to be rich and based on actors' perspectives, culture and context. In this study, qualitative data takes the form of discourses or other collections of words of different actors in the electricity sector to understand the current situation and futures.

3.2.6 Data collection techniques

Selecting a technique to collect qualitative data depends on what kind of data is sought, from whom and under what circumstances (Robson and McCartan, 2016). In a flexible design, the techniques can be added during the data collection period but it is essential to have an initial plan of how to collect data (ibid). The main techniques to collect qualitative data in flexible design are interviews, observations, focus group and content analysis of documents. The strengths and weaknesses of these techniques are summarised in Table 3.3. This section then provides the justification for the main data collection techniques in this study: semi-structure interviews and observation.

Table 3.3: Summary of strengths and weakness of data collection techniques in flexible design - adapted from Robson and McCartan (2016)

	Definition	Strength	Weakness
Interview	The researcher asks questions and receives responses from interviewees	- Stimulate communication. - Data are in the forms of words and rich.	- Bias of the interviewees.
Observation	The researcher observes human behaviours in their social settings.	- Data are contrasting. - Good for sense-making.	- Closed access - Data may not be used for analysis.
Documentary content analysis	The researcher searches for relevant documents and collect data from these documents	- Provide context for analysis.	- Bias from a specific remit. - Bias of publication (what is *not* published?)
Focus group	The researcher asks questions in a group and receives responses from interviewees in this group.	- Quick. - Encourage participants. - Stimulate debates. - Time consuming to organise!	- Need to be well-managed. - Confidential issues - unwilling to be open to discussion. - Conflicts can arise - Not suitable for time-poor senior figures

3.2.6.1 Interviews

Interviews are widely used to collect data in social science research and involve the researcher asking questions and receiving informative answers from interviewees (Robson and McCartan, 2016). As such, key actors can be questioned directly to explore and understand their perspectives and dominant discourses.

There are three types of interview (1) fully-structured, (2) semi-structured, and (3) unstructured according to Robson and McCartan (2016). The fully-structured interview has pre-determined questions with fixed wording, usually in a pre-set order (ibid). This type of interview is usually suitable for a research with clearly defined theories and conceptual frameworks (Bryman and Bell, 2011) and is less applicable in a flexible design (Robson and McCartan, 2016).

Unstructured and semi-structured interviews are both widely used in a flexible design. Unstructured interviews refer to "*open-ended*" and "*in-depth*" interviews without any prepared questions (Robson and McCartan, 2016). Through conversation, data are *unfolded*. Unstructured interviews are useful in situations where theory is absent and the purpose of the study is to produce theory. However, unstructured interviews can be time consuming for busy interviewees (Bryman and Bell, 2011) and there is a risk of not collecting enough data due to the lack of control over the interview structure and topics. For these reasons, unstructured interviews are not suitable in this study.

Semi-structured interviews are based on a checklist of themes (i.e. interview guide) to be discussed, but the wording and question order depends on the flow of the interview. This data collection technique is useful in situations where the researcher is interested in exploring a particular phenomenon without having an identified theoretical framework to account for this phenomenon.

An interview guide which covers relevant themes and topics to ask interviewees is required in semi-structured interview. Interview guides are "*the brief list of memory prompts of areas to be covered*" (Bryman and Bell, 2011). The task of the researcher is to identify a number of general topics which can help explore participants' perspectives but equally respect how participants response (Marshall and Rossman, 2016). Section 3.3 will discuss the development of this interview guide in detail.

3.2.6.2 Observation

Observation is usually undertaken to find out what is happening in a situation and often in an exploratory phase of research (Robson and McCartan, 2016). Participant observation was chosen and undertaken when attending industry-based workshops and conferences. However, it transpired that almost all of the workshops and conferences that the researcher attended were organised under the Chatham House Rule which states "*When a meeting, or part thereof, is held under the Chatham House Rule, participants are free to use the information received, but neither the identity nor the affiliation of the speaker(s), nor that of any other participant, may be revealed*." (Chatham House, 2002). Hence, in this study, observation is useful to gather views and discourses from different actors about futures and energy flexibility for the researcher's personal sense-making and interpretation.

3.2.6.3 Documentary content analysis

In flexible design, documentary content analysis can be used "a*t an early exploratory phase of the study where research questions are not fully developed*" (Robson and McCartan, 2016, p.353). Documents analysed could include books, reports, journal papers and media (articles in newspapers and TV and radio broadcasts). Documents on futures and energy flexibility published by the UK Government, National Grid, Ofgem and institutions are usually available via open access. At an early stage of this study, these documents helped to develop a deeper understanding about the context of the research phenomena and are valuable in understanding different dominant discourses for sense-making prior to semi-structure interviews. Documentary content analysis was used for reviewing literature, rather than for collecting data in this study.

3.2.6.4 Focus group

Focus group is used "*by political parties seeking to assess the likely response to proposed policies*" and is now widely used in social research (Robson and McCartan, 2016, p.298). It is one of the quickest methods to gather a large amount of data from different people (Robson and McCartan, 2016). It can helps the researcher easily "*assess the extent to which there is a consistent or shared view*" but also creates a situation for participants to "*make comments on their own words while being stimulated by thoughts and comments by others*" (Robson and McCartan, 2016, p.299). As such, it stimulates debate and discussions which may contain some interesting narratives and reveal power struggles between groups of actors. However, the researcher needs to manage the power relations in focus groups, otherwise, participants in focus group may hesitate to talk in depth about their views or organisational strategy which may prevent the researcher from collecting rich data. It is not either appropriate for time-poor senior figures in the industry. Hence, focus group is not chosen in this study.

Overall, in this study, data were primarily collected from semi-structured interviews. Observation is chosen to help the researcher with personal sense-making. The next section discusses sampling strategy which is an essential step before data collection.

3.2.7 Sampling strategy

Sampling is an important aspect of social research. A sample is defined as a selection of a population (Robson and McCartan, 2016). There are two sampling strategies (1) probability and (2) non-probability. Probability sampling involves the random selection of units of population (Bryman and Bell, 2011). Probability sampling is not relevant because this study is founded in logical constructionist ontology, which means knowledge is not attained through an objective manner. Non-probability sampling is therefore more suitable for the research.

In non-probability sampling, common sampling strategies include: (1) quota sampling; (2) dimensional sampling; (3) theoretical sampling, (4) convenience sampling; (5) purposive sampling and (6) snowball sampling. Of these, 5 and 6 were most relevant. *Quota sampling* is defined as "*a strategy to obtain representatives across different elements of the population*" (Robson and McCartan, 2016, p.80). Similarly, *dimensional sampling* is an "*extension*" of quota sampling in which "*at least one representative of every possible combination of dimensions is included*" (ibid). Obtaining representatives was not the goal of the research and thus quota and dimensional sampling are not selected. *Theoretical sampling* is also not relevant because it is mainly used in grounded theory research, not case study research. *Convenience sampling* strategy, as its name suggests, is adopted when participants are simply available to the researcher (Bryman and Bell, 2011, p.190). Although it can be used for the pilot of the primary data collection phase to provide the researcher with a "*feeling*" for the phenomena being investigated (Robson and McCartan, 2016, p.281), this study targets experts in the electricity sector, rather than from any convenient people.

Purposive sampling strategy enables the researcher to judge the selection and develop samples to meet the research aim and objectives (Robson and McCartan, 2016). In terms of this study, the researcher intended to choose samples from different groups of organisations across the supply chain of the industry, who play an important role in the current operation of the sector such as policy maker, Ofgem, National Grid, DNOs and suppliers. By doing so, the researcher is able to gather as many different perspectives about futures of the sector as possible. This sampling strategy may be criticised for the subjectivity of the researchers' selection (Marshall and Rossman, 2016). However, as identified in section 3.2.3, subjectivity should be embraced in social research and not be deemed as bias. In this study, the researcher identifies interviewees who are experts at high-level in an organisation (i.e. senior figures) who are able to provide the researcher with a deeper and rich insights into the phenomena than other general interviewees from the industry. This sampling strategy is in line with constructionism because it considers the subjectivity of participants willing to speak out their opinions and to talk about their organisations' strategies.

Snowball sampling strategy is viewed as "*a particular type of purposive sample*" (Robson and McCartan, 2016, p.281). Snowball sampling allows the researcher to identify one or two interviewees, then on the basis of information provided identify further interviewees (Robson and McCartan, 2016). This approach offers considerable utility in a highly flexible design and is suitable for qualitative research. As some actors are difficult-to-identify actors in the electricity industry, a snowball sample strategy will be useful.

One issue with this chosen snowball sampling strategy is that the researcher will not know in advance how many people are to be interviewed (Bryman and Bell, 2011). However, as the researcher collects qualitative data to generate a *thick description* of the phenomena from different perspectives, the number of interviews depends on the richness of the data collected. A natural end point arises when nothing *new* arises in further interviews or in other words, the research saturation point is reached (ibid). After adopting purposive sampling with some elements of snowball sampling strategy, data will be collected by semi-structured interviews. Data will then be analysed using techniques chosen in the following sections.

3.2.8 Data analysis techniques

There are three most common approaches to qualitative data analysis 1) quasi-statistical and 2) thematic coding technique and (3) grounded theory (Robson and McCartan, 2016). The choice of data analysis techniques is made based on the research design and aim and objectives of the study. Grounded theory which is used to build a theory in the grounded data is not selected because the research does not follow grounded theory research strategy. Quasi-statistical approach is not either chosen. It assumes that words and phrases which are frequently used are relatively important and normally used in content analysis (Marshall and Rossman, 2016). Such approach reduces qualitative data to quantitative data which is not relevant to the research where the interpretation of actors' discourses is much more important than the frequency of words. Besides, as this study is not based on data from content analysis, other techniques for data analysis are considered. This section sets out and justifies a thematic coding approach and how this works with discourse analysis.

3.2.8.1 Thematic coding analysis

The focus of qualitative data analysis in flexible research design is interpreting the situation the study is going to explore. Thematic coding analysis is a generic approach to analyse qualitative data in exploratory research (Robson and McCartan, 2016). It can be linked to different theoretical perspectives and be used from a constructivist perspective (Ibid).

Thematic coding analysis use codes to define what the analysed data are about. In semi-structured interviews, different groups of key actors may talk about the same topics relating to futures and energy flexibility, which can be coded with the same label. Data with the same label share the same interpretation. Codes are then grouped to make up themes which relate to the research aim and objectives. In this process of thematic coding analysis, data are *interpreted* rather than purely *described*. Moreover, in this process, codes can be identified from both data and the literature review. The process of thematic coding analysis allows the researcher to engage in an iterative process where the literature review informed data collection and data analysis. Data collection and analysis then stimulate further literature review, data collection and analysis.

Thematic coding analysis usually follows six phases (Braun and Clarke, 2006):

1. Familiarising with data: Data transcription, reading and re-reading data and jot down initial ideas

2. Generating initial codes: Coding interesting features of the data in a systematic fashion across entire dataset, collating data relevant to each code

3. Searching for themes: Collating codes into potential themes, gathering all data relevant to each potential theme

4. Reviewing themes: Checking if themes work in relation to the coded extracts (phase 1) and the entire data set (phase 2), generating a thematic map of the analysis

5. Defining and naming themes: Ongoing analysis to refine the specifics of each theme and the overall story the analysis tells, generating clear definitions and names for each theme

6. Producing the report: Final opportunity for analysis. Selection of vivid extract sampling, final analysis of selected extracts, relating back of the analysis to research question and literature, producing a scholarly report of the analysis.

These phases are looked at in details in section 3.3.2.1.

One of the challenges that the researcher faces during the process of data analysis is "*data overload*" which limits the ability of the researcher to process and analyse all data (Sadler, 1981). To support data analysis tasks the widely recommended and used NVivo 11 - a computer package specialised for analysing qualitative data was employed. Using NVivo provides increased flexibility in data analysis such as changes to the coding and analysis as new insights emerge.

3.2.8.2 Discourse analysis

Practically, analysing discourse can then be adopted after thematic coding analysis (Gill, 2000). Discourse analysis is based on the detailed examination of language (Robson and McCartan, 2016). It shows how language works within power relations or discursive power struggle between actors (Graham, 2011; Taylor, 2004). Discourse analysis following a Foucauldian approach is adopted in order to determine (1) some of the dominant energy discourse coalitions (research objective 1) and (2) futures of the sectors (research objective 2) (see section 2.6).

Each dominant energy discourse coalition hold different sets of assumptions about transitions to futures of the sector which then build a connection to deeper discourse analysis using energy discourse analytical framework (Table 2.4 described in section 2.6.1).

In summary, the data collected from this study will be analysed by thematic coding analysis and discourse analysis. The next section explores the issue of research quality.

3.2.9 Research quality

Criteria to evaluate trustworthiness of a flexible design research are contested. There are three positions regarding this matter (Steinke, 2004). The first position looks at transferring quantitative criteria to qualitative research. The second position denies the needs of having criteria to evaluate the quality of qualitative research. The third position calls for the needs to formulate quality criteria taking into account research aim and objectives, methods, specific features of the research field and the object of the investigation (Steinke, 2004, p.186). The section below justifies the use of the third position and selects quality criteria for this study.

The first position considers using quantitative criteria in qualitative research. Validity and reliability are two established terms to assess research quality following a fixed design or quantitative research. Validity of the research is "*being accurate, or correct or true*" (Robson and McCartan, 2016, p.169). Reliability is a degree of consistency in the research findings (Silverman and Marvasti, 2008) from a particular data collection methods (Robson and McCartan, 2016). Morse (1999) advocates using validity and reliability arguing that qualitative research is science and in science, good research should be reliable and valid. Popular quality criteria for qualitative research following this position transferred from quantitative criteria are internal validity, external validity, reliability and objectivity (Yin, 2009). Conversely, some researchers deny the use of these criteria (Lincoln and Guba, 1985; Marshall and Rossman, 2016; Robson and McCartan, 2016) because they are used to evaluate quality of a fixed design research. Here, using validity and reliability is problematic because there is no consensus on whether these criteria are relevant to qualitative research (ibid). Moreover, quantitative criteria are developed from different methods, based on different ontology and epistemology such as positivism. While this study follows constructionism, using the quantitative criteria with different basic assumptions is incompatible (Steinke, 2004).

The second position goes against the establishment of qualitative research quality criteria (Wolcott, 1994). Researchers "*write their text in the first person singular*"; and overcome "*the division between the observer and observed reality*"; hence, these researchers do not need to care about reliability and validity (Steinke, 2004). However, this position is not useful in this study because it risks randomness and arbitrariness. As such, this position can limit the study in a "*scientific community*" and put the researcher in the difficult situation of convincing others of the value and quality of their studies (Lincoln and Guba, 1985).

The third position offers some alternative qualitative criteria:

- Credibility through documenting the research process (Steinke, 2004)
- Transferability in terms of analytical generalisation rather than statistical generalisation (Yin, 2009)

Credibility is about whether the story developed by the study is trusted. Trust can be established via an open and transparent research process. According to Padgett (1998), credibility can be obtained from a "*prolonged involvement*" and by providing an audit trail.

Transferability is concerned with the generalisation of the study. As mentioned in section 3.2.4, generalisability (i.e. statistical generalisation) is not an issue for this study because this study follows a case study strategy where deep understanding of the focal phenomena is more important than generalising the outcome to other contexts. However, analytical generalisation (of qualitative research) which differs from statistical generalisation (of quantitative research) can be replaced. Analytical generation refers to the application of theoretical propositions or conceptual perspective in other cases with similar characteristics (Yin, 2009).

Triangulation is needed to counter the threats to the trustworthiness of the study (Robson and McCartan, 2016, p.171). Triangulation is defined as "*the use of more than one method or source of data in the study of social phenomenon so that findings may be cross-checked*" (Bryman and Bell, 2011, p.720). In this study, triangulation was achieved by collecting data from more than one source (as detailed in section 3.3.1), including:

- Semi-structured interviews with 28 senior figures in GB's electricity sector. Interviewees were purposively selected from different organisations across the sector's value chain spanning generation, distribution and consumption of electricity; and
- Observations of 27 industrial-based conferences such as the Westminster Energy Forum (WEF), conferences hosted by Energy UK (a trade association for the energy industry) or by British Institute of Energy Economics (BIEE), gathering organisations and individuals from various backgrounds and with concerns about energy and its transitions; and
- Grey literature including white papers, government and industry reports, working papers, press releases and newspaper articles published by the UK government, Ofgem, National Grid, DNOs, energy suppliers, independent research institutes, energy trade associations and so on.

Data collected via the semi-structured interviews were analysed using a thematic approach and thus triangulation was achieved within this dataset. Further, observations in the form of notes taken at the industrial-based conferences and the use of grey literature were cross-checked with data collected via semi-structured interviews, enabling data to be further triangulated and contextualised.

3.2.10 Research ethics

As this study seeks to explore futures with human participants, research ethics were considered. Bryman and Bell (2011) summarised four key areas where ethical concerns are able to arise. These are (1) Harms to participants (2) informed consent (3) invasion of privacy and (4) deception.

3.2.10.1 Harm to participants

Harm can be physical harm, mental harm or even harm to future employment (Bryman and Bell, 2011). The research was conducted in accord with the Open University Code of Practice for research involving the collection of data from human participants. Ethics review by the Human Research Ethics Committee (HREC) provides a mechanism for assuring the ethical integrity of research. The risks to human were assessed by HREC on the basis of a risk checklist fulfilled by the researcher and checked by supervisors. By doing so, the researcher identified that there is no risk of harm to participants arising from the study. Some main highlights are as below:

- The study does not involve any vulnerable people
- There is no necessity for participants to take part in the study without their knowledge and consent
- The study does not involve discussion of sensitive topics.
- The study does not involve the sharing of data or confidential information beyond the initial consent given.
- The study does not induce any psychological stress or anxiety or cause harm or negative consequences beyond the risks encountered in normal life.
- The study does not take place outside the UK
- The study does not involve participants responding via internet or visual methods where participants may be identified.

An information sheet and consent form for participants were attached together with the mentioned checklist of risks to HREC to assess. Ethics approval for the research was obtained (Ref: HREC/2018/2761/Nguyen).

3.2.10.2 Informed consent

Consents of participants need to be sought before conducting interviews to avoid harm to participants. Informed consent entails that even when people know they are being asked to participate in research, they should be fully informed about the research process (Bryman and Bell, 2011). Before conducting interviews, the researcher sent participant information sheets to describe the study, the researcher and information in relation to the research process. A consent form with signatures from both participant and the researcher were obtained before collecting data from interviews. This consent form highlighted (1) participants can withdraw from the research and can refuse to answer any questions (2) participants and their organisations are anonymised, (3) the interview will be audio-recorded but interviewees can decline the recording and (4) data will be stored securely and will be destroyed after 10 years following the completion of the study which is estimated to be 31 Jan 2030. The information sheet and consent form for participants are found in Appendix B.

3.2.10.3 Invasion of privacy

Privacy can be linked to the concept of "*informed consents*" because by giving informed consents to the researcher, participants acknowledged that their privacy has been surrendered for that limited domain (Bryman and Bell, 2011). In the consent forms, the researcher allowed the participants to reserve the right to refuse to answer any question. By doing so, the researcher respected the privacy of participants.

3.2.10.4 Deception

Deception relates to the situation when the researcher present their research as something other than what it is (Bryman and Bell, 2011). In this study, the researcher collected data to explore the futures of GB's electricity sector and stated this aim clearly with participants. Hence, deception is not relevant in this study.

3.2.10.5 Other ethical issues

One other ethical issue for this study is data protection in compliance with General Data Protection Regulation (GDPR). Data collected were kept securely in a password-protected laptop and backed up on password-protected One Drive of the Open University. Only the researcher and supervisors have access to this. Any printed copies were kept securely in locked cabinets.

3.2.11 Summary

In summary, this section detailed methods selected for this study, which follows *a flexible design* based on a *holistic case study* of GB's electricity sector. The study was developed via an iterative process following *constructionism*. The research process is conceptualised as *a progressive funnel* where the study is gradually focussed. Qualitative data will be collected in the form of words primarily via *semi-structured interviews*. *Purposive sampling strategy* with some elements of *snowball sampling strategy* will be followed by data analysed using *thematic coding and discourse analysis*. The researcher can ensure the criteria of this study by making sure that the study meet *credibility and transferability*. Research ethics can be ensured by having *informed consents* in place.

3.3 RESEARCH DESIGN APPLICATION

The application of the flexible study design incorporating the above is described in the following section.

3.3.1 Data collection

Interviews were conducted throughout the study to collect data from 28 interviewees in GB's electricity sector (Appendix D). Interviewees in this study were selected on the basis of expertise and insights into the sectors. Information regarding the research process were given to interviewees by the information sheet (Appendix B) and were reminded again before each interview.

These interviews were carried out in two phases, reflecting the iterative processes that the researcher followed, as described below.

3.3.1.1 Phase 1 of interview ***(from Feb 2018 to June 2018)***

In this phase, the interview guide prepared by the researcher was exploratory. Questions were used to prompt the interviewees who were then free to interpret the questions and respond. The researcher's tasks here was to make sure that the flow of the conversation was smooth and key themes were explored within the time set, which was about one hour per interview. However, depending on the requirements from interviewees, the interviews could be within half an hour or up to two hours. The purpose of these exploratory semi-structured interviews was to gain insights into the themes that the researcher selected and to gain interviewing experience.

The selected main themes for interview guides were (1) Current situation, (2) Changes and (3) Futures. The guide is shown in the Appendix C.

Interviewees in this phase were selected purposively to provide the researcher with a *big picture* of GB's electricity sector. These interviewees are experts with general insights about GB's electricity sector in the development of the sector. At this stage, a list of interviewees was developed, which was gradually revised in line with the development of the study. This list includes following elements:

- No: the identification number of the interviewee, this number is identical for each interviewee and would be used in Chapter 4 and 5 when extracting quotes
- Actors/ Perspective: Perspectives of the interviewee
- Proposed organisations: the organisation/ division that the interviewee is working in

- Proposed name: name of the interviewee
- Justification:

  Phase 1: General insights of the sector

  Phase 2: Interviewees with different perspectives/ roles across the electricity value chain.
- Interviewees suggested also to speak with: Snowballing sampling strategy was reflected here.
- Contact details: Usually email address of the interviewee
- Notes: The process of getting accessed is reflected here, whether the interviewee has been contacted, whether they have responded, etc.
- Updated + date: The outcome of the interview arrangement is updated here, whether the interviewee is done, when is the appointment, whether the interviewee is prioritised to be interviewed. This column is colour-coded for the researcher to easily prioritise interviewing tasks.

In this first phase, the researcher interviewed 7 interviewees. Anonymised details of are in Appendix D. These interviewees were informed about the interview and the study before taking part in the interviews to ensure that ethical issues were not violated. After these interviews, initial codes and themes which represent "*interesting features*" of the interviews were identified (see section 3.3.2.1.2), together with literature review in an iterative process, Phase 2 was conducted.

3.3.1.2 *Phase 2 of interview* ***(from November 2018 to June 2019)***

In this phase, the interview guide was also exploratory. However, the themes in the interview guide changed following iterative processes through further reviewing the literature in line with analysing the data collected from Phase 1. The themes became more focused with the topics that the first 7 interviewees mentioned and from further literature review. They are:

- Changes
- Innovations (Technology and Business model)
- Stability
- Policy, regulation and market
- Organisational culture
- Investment

- Consumers
- Power
- Timeframe

The first theme that the research asked was "*changes*" due to identifying that actors in GB's electricity sector usually start their responses with changes. After that, the order of the themes was not fixed. The researcher asked questions based on the flow of the conversations.

Interviewees in this phase were selected purposively with some elements of snowball sampling strategy (i.e. one interview led to another). The researcher looked at the elements in the value chain of the GB's electricity sector to identify organisations of interviewees. The value chain is defined as "*set of activities that a firm operating in a specific industry performs in order to deliver a valuable product (good and/or service) for the market*" (Porter, 2008). In GB's electricity sector, the value chain consists of generation, distribution (and transmission) and consumption. These main elements can be made up of incumbents or new entrants. The operation of these elements is administrated by a system operator. The electricity market is also overseen by a regulator and the code of operation for this market is managed by some code administrators. The overall sector is governed by the policy from government. The value chain is identified from understanding the current sectors' actor from data collected from Phase 1. Here, interviewees in Phase 2 represent different organisations which operate GB's electricity sector.

The process of identifying key organisations relevant to this study is reflected in the actor map (Figure 3.4). At this stage, the researcher did not confirm that representatives from all these organisations needed to be found and interviewed.

After identifying the potential organisational types and organisations, interviewees were identified using either purposive or snowballing sampling strategy from interviewees' suggestions. The list of interviewees was updated and revised as the study proceeded. The list in Phase 2 has 30 proposed interviewees who are senior figures of GB's electricity sector. However, only another 21 interviews were conducted until the interviewing process reached the saturation point. Anonymised details of 21 interviewees are in Appendix D.

3.3.1.3 Observation

During this research, the researcher has attended in person 27 industrial-based seminars and conferences before national lock-down (see Appendix E). For example, the Westminster Energy Forum (WEF) which contains more than 150 public and private organisations with concerns about energy transitions. Although notes taken from these seminars and conferences were not used for

Figure 3.4: Actor map – Developed in phase 1 of interviews

data analysis specifically, these helped the researcher gain significant knowledge of the sector and pressures for change, identify key actors and make connections to them.

3.3.2 Data analysis

After data were collected, transcriptions were produced. Data from Phase 1 interviews were analysed manually using highlights and post-it notes. Then, data from both Phase 1 and Phase 2 interviews were added to N-Vivo. Firstly, data were analysed using thematic coding analysis to interpret the transitions of GB's electricity sector. Secondly, data were analysed using discourse analysis to identify actor constituencies and articulate futures of the sector. These processes are described below.

3.3.2.1 Thematic coding analysis

Thematic analysis goes beyond the mere description of the situation, rather it seeks to provide interpretation of the situation which emphasises the significance of themes, their meanings and implications (Patton, 1990). The thematic approach to data analysis was developed to interpret the transition of GB's electricity sector with different actor visions and expectations, i.e. assumptions. The themes were constructed from codes found in the literature and from data, following six phases (see section 3.2.8.1). However, following these six phases does not mean that analysis is a linear process where the researcher moves to a next phase after finishing a phase. These analytical phases are recursive as needed. This *recursive* process is relevant to the iterative process as this study follows. The first five phases are described in the following sections while the last phase (producing the report) is presented in Chapter 4.

3.3.2.1.1 Phase 1: Familiarising with data

The first phase of thematic coding analysis requires "*immersing*" in the collected data. Immersion involves the process of reading and "*repeated reading*" and searching for meanings and patterns and so on (Braun and Clarke, 2006). This process is time-consuming; thus, qualitative research usually uses smaller samples than, for example, quantitative research from questionnaires (ibid). If the data collected is verbal, for instance from semi-structure interviews, transcribing can contribute to immersing with the collected data (Riessman, 2005). Transcription of 28 interviews have been done after each interview. As such, the time spent in transcription was not wasted. Transcription could form this early phase of analysis. The researcher added some notes onto the transcripts when transcribing the interviews. The transcripts were then re-read during the process of analysis to increase the familiarity with data.

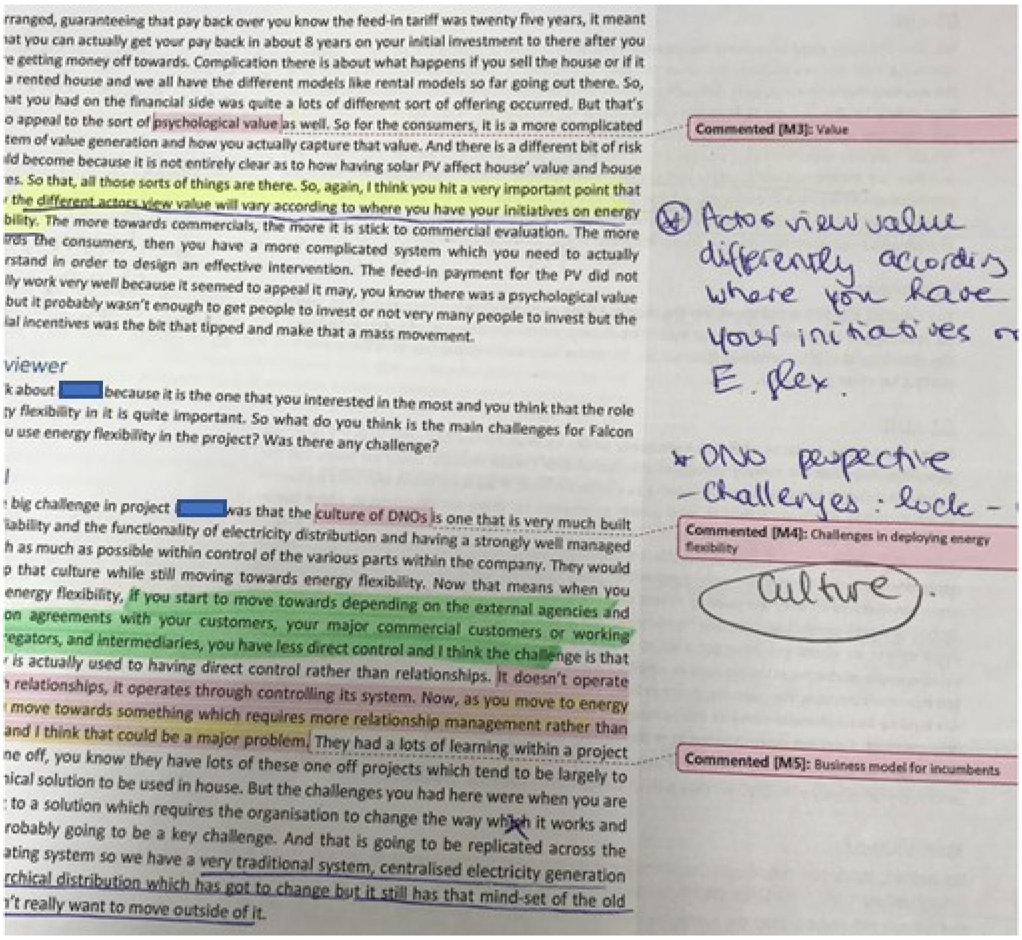
3.3.2.1.2 Phase 2: Generating initial codes

The second phase of thematic coding analysis involves organising data into meaningful groups (Tuckett, 2005). This phase can be started once the researcher was familiar with the data. The researcher worked through the entire data set and gave full and equal attention to each data item to identify interesting aspects in the data items that may form codes (Braun and Clarke, 2006). Seen in this way, codes represented an interesting feature of data. The researcher coded for the as many potential interesting features as possible.

Coding can be done manually or through a software such as NVivo (Seale, 1999). In this study, the researcher performed analysis both by hand and through NVivo 11. Usually, qualitative analysis software is suitable when a predetermine coding structure is available (Auld *et al.*, 2007). The process of coding at the beginning was data-driven. As such, it was not suitable to use software to code at this stage. Coding through NVivo was adopted after code structure has been determined and when the amount of data became larger. At the later stage, NVivo allows the researcher to better manage the large amount of data.

At the manual coding stage, the researcher printed transcripts of the first 7 interviews, read the transcripts to identify "*interesting features*" of the text (Braun and Clarke, 2006). At this stage, following Braun and Clarke (2006), the researcher looked for as many potential themes/patterns as possible as these themes/patterns may become interesting later. Individual extracts of data can be coded in different themes/patterns and the surrounding data is kept to ensure that the context is not lost (Bryman and Bell, 2011). At this stage, notes were written on the printed-out copies of transcripts as illustrated in Figure 3.5. The blue boxes on this figure are redactions to protect confidentiality.

After writing notes about codes on the printed-out transcript, the researcher summarised them onto a table with three columns: (1) Code; (2) Description of the code and (3) Direct quotes. This table is illustrated in Figure 3.6. With this table, the researcher could be clear about the meaning of each code which then contributed to the grouping codes to make themes. After a list of codes has been produced, the researcher started the third phase of thematic coding analysis which is searching for themes.


rranged, guaranteeing that pay back over you know the feed-in tariff was twenty five years, it meant hat you can actually get your pay back in about 8 years on your initial investment to there after you e getting money off towards. Complication there is about what happens if you sell the house or if it a rented house and we all have the different models like rental models so far going out there. So, hat you had on the financial side was quite a lots of different sort of offering occurred. But that's o appeal to the sort of psychological value as well. So for the consumers, it is a more complicated tem of value generation and how you actually capture that value. And there is a different bit of risk ld become because it is not entirely clear as to how having solar PV affect house' value and house es. So that, all those sorts of things are there. So, again, I think you hit a very important point that the different actors view value will vary according to where you have your initiatives on energy bility. The more towards commercials, the more it is stick to commercial evaluation. The more rds the consumers, then you have a more complicated system which you need to actually rstand in order to design an effective intervention. The feed-in payment for the PV did not lly work very well because it seemed to appeal it may, you know there was a psychological value but it probably wasn't enough to get people to invest or not very many people to invest but the ial incentives was the bit that tipped and make that a mass movement.

viewer

k about [redacted] because it is the one that you interested in the most and you think that the role y flexibility in it is quite important. So what do you think is the main challenges for Falcon u use energy flexibility in the project? Was there any challenge?

big challenge in project [redacted] was that the culture of DNOs is one that is very much built iability and the functionality of electricity distribution and having a strongly well managed h as much as possible within control of the various parts within the company. They would p that culture while still moving towards energy flexibility. Now that means when you energy flexibility, if you start to move towards depending on the external agencies and on agreements with your customers, your major commercial customers or working regators, and intermediaries, you have less direct control and I think the challenge is that is actually used to having direct control rather than relationships. It doesn't operate h relationships, it operates through controlling its system. Now, as you move to energy move towards something which requires more relationship management rather than and I think that could be a major problem. They had a lots of learning within a project ne off, you know they have lots of these one off projects which tend to be largely to ical solution to be used in house. But the challenges you had here were when you are to a solution which requires the organisation to change the way which it works and robably going to be a key challenge. And that is going to be replicated across the ating system so we have a very traditional system, centralised electricity generation rchical distribution which has got to change but it still has that mind-set of the old 't really want to move outside of it.

Commented [M3]: Value

Actors view value differently according where you have your initiatives on E. flex.

DNO perspective
- Challenges : lock -

Commented [M4]: Challenges in deploying energy flexibility

Culture.

Commented [M5]: Business model for incumbents

Figure 3.5: Notes of codes on transcripts (Phase 2 of thematic coding analysis)

Code	Description of code	Direct quote
Decarbonisation	Decarbonisation is an important aspect of the industry, but different interviewees view decarbonisation differently. They view them as a target which enables change (02, 03), or as challenges to overcome (05REG, 06).	02: Then ultimately, what I am talking about is all of this is in the context of 80% decarbonise UK economy, so I am just assumed that this is a very decarbonised electricity system because that is what I expect. So, it allows you to deliver that decarbonised energy system, not necessarily at least cost, but avoided unnecessary costs. 03: There is a framework for change behind that so we got a decarbonisation plan that should decarbonise the system by 2050 ...So many other kinds of target around that. 05 REG: Well in no particular order, one clear challenge which is being present now for the last 15 years is decarbonisation of the sector. And it's very much work in progress but as you know the country has international legal obligations to meet in relation to reduction in CO2 production and that doesn't impact only the electricity sector it affects all sorts of aspects of the economy. ... So the decarbonisation activity has been profound and has led to significant change in the sector. But still working progress, we've got plenty to do there. So that's one challenge. 06: I think that was relatively straightforward. We have a very clear vision, from the government. 2050 is the date, we have what's called the trilemma clean, secure, affordable but the clean bit is very specific which is 80 percent reduction relative to 1990. We have real challenges for the next carbon budget because at this point in time we are challenged to get to those budgets. And I also think for the 2050 days it's reasonably likely that the world as long as America participation in this, will decide to go even further than 80 percent by 2050. So the low-carbon transition drives absolutely everything. It's driven electric vehicles, etc.

Figure 3.6: Example of a code with description and illustrated quotes (Phase 2 of thematic coding analysis)

3.3.2.1.3 Phase 3: Searching for themes

The third phase of thematic coding analysis involves considering different codes and grouping them into themes (Braun and Clarke, 2006). A theme "*captures something important about the data in relation to the research question and represents some level of patterned response or meaning within the data set*" (Braun and Clarke, 2006, p.10). The researcher began this phase with all the codes identified above. Codes might form themes, sub-themes or be discarded. Codes were collated into "*candidate themes*" which means not-yet-final-themes. These candidate themes were to be reviewed and reworked in subsequent phases of thematic coding analysis. The researcher used post-it notes to map the codes into candidate themes as shown in Figure 3.7.

These post-it notes were arranged and re-arranged into meaningful groups or discarded. These initial arrangements were firstly guided by the data and by the research aim. Candidate themes and subthemes were initial identified in Table 3.4.

The output of this phase was predominantly descriptive. The process of thematic coding analysis in this study was an iterative process in the sense that while the candidate themes were data-driven in this phase, the researcher kept reviewing literature and collecting data. By doing so, the researcher realised that searching for themes should also be facilitated by some literature, especially from the Multi-level perspectives. Besides, these candidate themes were too complicated with many sub-themes and overlapped which may mean that lack of sufficient data to support them at later stage. As such, the next phases of thematic coding analysis were conducted.

3.3.2.1.4 Phase 4: Reviewing themes

This phase involves the refinement of candidate themes. This phase is required to ensure that candidate themes are revised several times. Once a list of candidate themes is set, this researcher

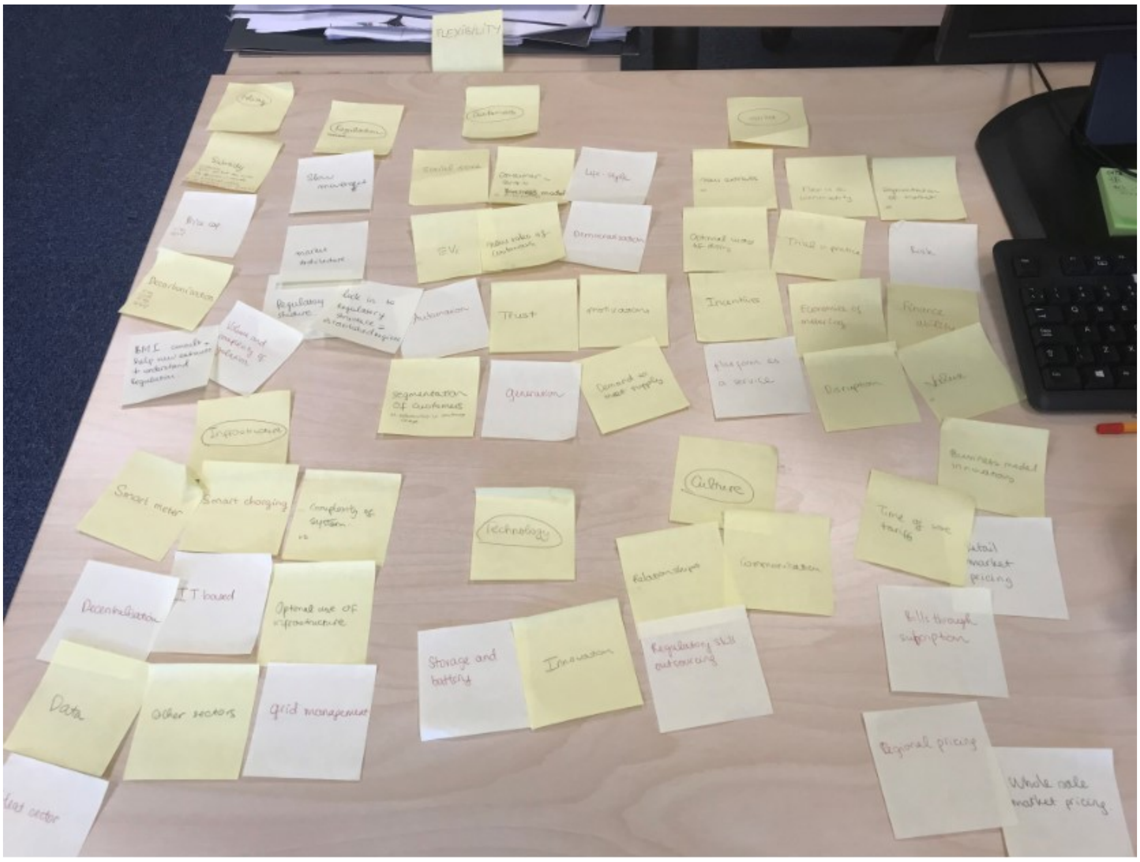


Figure 3.7: Searching for themes by post-it notes (Phase 3 of thematic coding analysis)

Table 3.4: Initial candidate themes identified in Phase 3 of thematic coding analysis

1.	**Consumers**: Domestic consumers and Business consumers who consume energy.
2.	**Disruption**
3.	**Flexibility**: energy flexibility, the ability to keep the system in balance at all time
4.	**Financial ability**: the ability to finance electricity generation projects
5.	**Optimal use of infrastructure**: how to make the most of the current infrastructure?
6.	**Consumer-centric business model**
7.	**Innovation**
8.	**Platform as a service**
9.	**Market**
10.	**Regulatory structure**
11.	**Time frame**
12.	**Culture**

can begin this phase. This phase consists of two levels of reviewing. Firstly, all the coded extracts for each theme must be reviewed to make sure that they form a coherent pattern. Secondly, this process is conducted with the whole dataset (Braun and Clarke, 2006). In order to examine all the coded data extracts, the researcher started using NVivo 11. Figure 3.8 shows an example of data nodes in NVivo.

Nodes

Name	Sources	References	Created On	Created By	Modified On	Moc
ITV Consumers	19	114	03/07/2018 08:38	MNN	15/12/2019 21:16	MN
ITV Consumers change behaviour	11	27	06/05/2019 16:09	MNN	05/01/2020 00:54	MN
ITV Consumers - give them control	2	2	06/05/2019 16:12	MNN	27/07/2019 18:54	MNI
ITV Consumers - give them data	3	3	06/05/2019 16:18	MNN	04/09/2019 12:05	MNI
ITV Consumers - give them motivation	5	10	06/05/2019 16:11	MNN	23/06/2019 23:26	MNI
ITV Consumers - give them technologies	6	9	06/05/2019 16:18	MNN	05/01/2020 00:55	MNI
ITV Smart meter	5	5	06/05/2019 16:19	MNN	18/06/2019 13:05	MNI
ITV save bill for them	1	1	21/05/2019 14:23	MNN	05/01/2020 00:55	MNI
ITV Consumers don't engage	11	18	06/05/2019 16:08	MNN	05/01/2020 00:55	MN
ITV Consumers are not ready	1	1	06/05/2019 16:51	MNN	06/05/2019 16:51	MNI
ITV Consumers don't act rationally	1	2	06/05/2019 16:47	MNN	21/05/2019 14:27	MNI
ITV Consumers don't want to own things	1	1	06/05/2019 16:47	MNN	26/06/2019 23:31	MNI
ITV Industries don't care about offering consumers products	5	6	06/05/2019 16:41	MNN	04/09/2019 12:05	MNI
ITV Price of energy is too cheap	1	1	20/05/2019 14:39	MNN	20/05/2019 14:39	MNI
ITV Consumers' relationship	2	2	06/05/2019 16:22	MNN	05/01/2020 00:55	MN
ITV Relationship with energy conpanies	1	1	28/03/2019 14:22	MNN	28/03/2019 14:23	MNI
ITV relationship with network companies	1	1	02/04/2019 10:41	MNN	02/04/2019 10:41	MNI
ITV Engagement	12	27	03/07/2018 08:40	MNN	05/01/2020 00:55	MN
ITV Consumers act rationally	4	4	27/03/2019 23:38	MNN	28/05/2019 17:31	MNI
ITV Consumers follow trends	1	1	21/05/2019 21:35	MNN	21/05/2019 21:36	MNI
ITV Passive consumers	2	2	29/03/2019 12:44	MNN	30/05/2019 08:26	MNI
ITV price of electricity is expensive	1	1	06/05/2019 16:13	MNN	06/05/2019 16:13	MNI
ITV Segmentation of consumers	11	26	03/07/2018 08:59	MNN	05/01/2020 00:55	MN
ITV industrial consumers vs domestic consumers	2	3	06/05/2019 16:21	MNN	06/05/2019 16:21	MNI
ITV Life-style	2	4	03/07/2018 09:01	MNN	07/04/2019 18:42	MNI
ITV Social issue	3	5	03/07/2018 09:00	MNN	12/09/2019 10:08	MNI
ITV Trust	6	11	03/07/2018 08:44	MNN	05/01/2020 00:55	MN
ITV trust on big suppliers vs new entrants	1	1	06/05/2019 16:54	MNN	19/05/2019 23:00	MNI
ITV trust on big suppliers vs network companies	0	0	06/05/2019 16:54	MNN	06/05/2019 16:54	MNI

Figure 3.8: Coding in NVivo (Phase 4 of thematic coding analysis)

By coding in NVivo, the researcher repeated Phase 2 and 3 of the thematic coding analysis. This repeating process is normal in thematic coding analysis, especially coding which is the on-going process in thematic coding analysis. NVivo allowed the researcher to deal with a large amount of data set. The structure of the nodes on NVivo could be changed to reflect the potential themes and sub-themes. Using reporting functions in NVivo, the researcher printed out the nodes structures to easily re-arranged the nodes. An example of a node structure was shown in Figure 3.9.

Node Structure
Energy flexibility in transition
07/05/2019 00:41

Hierarchical Name	Nickname	Aggregate	User Assigned Color
Node			
Nodes			
Nodes\\ITV Change		No	None
Nodes\\ITV Change\ITV changes is good		No	None
Nodes\\ITV Change\ITV How change happen		No	None
Nodes\\ITV Change\ITV Speed of change		No	None
Nodes\\ITV Change\ITV Speed of change\ITV Fast change		No	None
Nodes\\ITV Change\ITV Speed of change\ITV Slow change		No	None
Nodes\\ITV Consumers		No	None
Nodes\\ITV Consumers\ITV Consumers change behaviour		No	None
Nodes\\ITV Consumers\ITV Consumers change behaviour\ITV Consumers - give them control		No	None
Nodes\\ITV Consumers\ITV Consumers change behaviour\ITV Consumers - give them data		No	None
Nodes\\ITV Consumers\ITV Consumers change behaviour\ITV Consumers - give them motivation		No	None
Nodes\\ITV Consumers\ITV Consumers change behaviour\ITV Consumers - give them technologies		No	None
Nodes\\ITV Consumers\ITV Consumers change behaviour\ITV Consumers - give them technologies\ITV Smart meter		No	None

Figure 3.9: Node structure in NVivo (Phase 4 of thematic coding analysis)

More usefully, NVivo has a function of printing out all the data extracts of nodes. The researcher could easily use this function to check if the data extracts reflected the potential themes and formed a coherent pattern which was involved in the first level of this reviewing theme phase. An illustration of the data extracts printing out from NVivo is shown in Figure 3.10. The orange boxes on this figure are redactions to protect confidentiality.

Coding Summary By Node

Energy flexibility in transition

22/06/2019 09:34

Aggregate	Classification	Coverage	Number Of Coding References	Reference Number	Coded By Initials	Modified On

Node

Nodes\\ITV Future\ITV Smart grid\ITV Consumers - not engaged

Document

Internals\\Interview\\04

Aggregate	Classification	Coverage	Number Of Coding References	Reference Number	Coded By Initials	Modified On
No		0.0040	1			
				1		18/06/2019 11:09

Because our view is that the consumers won't go on the platform and say you can shift my fridge or turn if off in this half hour to get 30p, our view is that it is the market that is not gonna work.

Internals\\Interview\\24

Aggregate	Classification	Coverage	Number Of Coding References	Reference Number	Coded By Initials	Modified On
No		0.0059	1			
				1		18/06/2019 07:39

Yeah well I mean the secret is automation, so all of our innovation projects have shown that there is there is small there is a small group of consumers who want to be highly engaged and they sit on the phone or their apps to turn things on and off and that's great.

Nodes\\ITV Future\ITV Smart grid\ITV Consumers' expectation changes

Document

Internals\\Interview\\19

Figure 3.10: Data extracts from N-Vivo (Phase 4 of thematic coding analysis)

By reading these data extracts, the researcher reviewed candidate themes and sub-themes. This process was stopped when the researcher felt that further amendments did not add anything substantial. After this phase of thematic coding analysis, a new list of candidate themes was gathered, which is shown in Table 3.5.

After the list of candidate themes was reviewed and no more substantial amendment was made, these themes were defined in the following section.

Table 3.5: Developed candidate themes, identified in Phase 4 of thematic coding analysis

Themes	Subthemes
1. Consumers	Consumers change behaviour Consumers' relationship Consumers Trust
2. Culture	Skill sets
3. Flexibility	Current flexibility Future of flexibility Value of flexibility
4. Governmental policy	Decarbonisation Goal of system
5. Innovation	Business model innovations Financial innovations Innovation barriers Technological innovations
6. Market	Competition Investment Pricing mechanism Market architecture Trial vs upscale Whole-sale market price
7. Network	Barriers for network flexibility Futures of network Network challenges
8. Regulatory structure	Purposes of regulation Regulatory criticism Future of regulation
9. System Lock-in	Lock-in due to - Naysayer Lock-in due to bias of centralisation Lock-in due to Lack of skills needed Lock-in due to regulator

3.3.2.1.5 Phase 5: Defining and naming themes

The phase of defining and naming themes started when the satisfactory list of themes was produced. At this phase, an overarching narrative should begin to emerge, with the data telling a story in relation to the research aim. It is important to identify not only the story that each theme tells, but also how these individual story fits with the overall story about the collected data, in relation to the research aim. At this stage, the researcher needs to identify what is interesting about the data and why, rather than "*just*" paraphrase the content of the data extracts (Braun and Clarke, 2006, p.22).

At the end of this phase, the researcher would be able to clearly define each theme and its scope. Names of each theme should be revised if needed in order to give reader a sense of what the theme is about. The names and definitions of final themes are shown in Table 3.6.

The review of themes suggested that some developed themes did not require further exploration but belong to "*broader*" themes which facilitate the stories about transitions of GB's electricity

Table 3.6: Final analytical themes with definitions

Themes and definition	Subthemes and sub-subthemes
1. Change: current changes that are happening now and innovations (both technological and business model innovations) in each sub-system. Innovations are likely to be multiple, architectural and consumer-centric.	- Generation: low carbon technologies, more actors involving in generation, large-scale storage batteries connecting to transmission grids. - Consumption: further uptakes of EVs, market trials of technologies, more important role of consumers, different perspectives on consumer engagement, continued rollout of smart meter and smart home appliances, time-of-use tariff model supported by smart-phone apps, energy service companies, consortia. - Distribution: bilateral contracts in wholesale market, smart grids, flexibility platforms, technology platform.
2. Timeframe and nature of change: differences in interviewees' perspectives of timeframe of innovations and transitions which then reflect incremental nature of changes.	- Timeframe of innovations: smart meters and EVs. - Timeframe of transitions: slow, quick or unknown.
3. Stability: the "lock-in" to current systems and barriers which prevent transitions from occurring.	- Stability is essential: fundamental physics of the system. - Stability is a barrier: different interviewees' perspectives on different barriers. • Technological barriers: batteries in EVs, technologies to procure Black Start. • Financial barriers: cost of technology (EV batteries, reduction in cost), financial incentives (cost-savings from DSF, economic rational behaviour of consumers), subsidy (subsidy supports low carbon technologies, subsidy stifles innovations). • Organisational cultural barriers: traditional mindset (centralisation mindset of incumbents), skill sets (new skills, organisational leaders do not have new skills, the regulator does not have new skills). • Consumer barriers: consumer trust towards incumbents and new entrants. • Informational barriers: consumer data, network data. • Market design barriers: market design in terms of storage, complexity of regulatory licenses and codes.
4. Regulation and policy: the role of regulation and policy in transitions	- Regulatory structure: regulation is a barrier; the whole regulatory structure needs to change. - Energy policy: certainty from energy policy, direction of transitions from energy policy, energy policy is not needed.
5. Goals of transitions: potential goals of transitions according to interviewees' commentaries.	- Decarbonisation: decarbonisation is a transition goal; decarbonisation is a challenge. - Energy flexibility: energy flexibility is a transition goal, energy flexibility is "problems and solutions" of the sector.

sector. The final themes are change, timeframe and nature of change, stability, regulation and policy, and goals of transition (decarbonisation and energy flexibility) as shown in Table 3.6. These themes were defined and ready for the reporting phase (phase 6 of thematic coding analysis) which will be described in Chapter 4.

This section describes the iterative process of thematic coding analysis that the researchers adopted in this study which reflected as a research funnel of this study. This thematic coding analysis was conducted to make sense of transitions of GB's electricity sector. The findings from the thematic coding analysis are described in Chapter 4. The following section explains how the different discourse coalitions were identified, as part of discourse analysis to identify different futures of GB's electricity sector.

3.3.2.2 Discourse analysis

After thematic coding analysis, interpretations or assumptions of interviewees about transitions to futures of GB's electricity sector were revealed. These different assumptions were compared with different sets of assumptions of contemporary energy discourses from literature identified in section 2.6.2 to divide actors into different coalitions. Some dominant energy discourse coalitions were identified and described at the end of Chapter 4.

After that, deeper energy discourse analysis was undertaken to explore futures articulated by each of these discourse coalitions. This analysis followed the energy discourse analytical framework identified in Table 2.4. For pragmatic reason, each discourse coalition is assumed to articulate one future of the sector. The findings are described in Chapter 5.

3.3.3 Difficulties

The researcher encountered several difficulties in applying research design, including:

Firstly, by interviewing senior figures in different organisations across the value chain of the electricity sector, the researcher is able to capture different perspectives of actors and explore their visions and expectations about the development of the sector. It is valuable for the researcher to gain industrial insights while most research in the field does not include data from senior figures. However, accessing senior figures in the industry was not easy and far slower than anticipated, even with the facilitation of the researcher's industrial supervisor who is Vice President of CGI.

Secondly, the researcher has thought about organising a couple of workshops with CGI – the industrial sponsor and other industrial actors to evaluate the collected data from semi-structured interviews. However, it became unfeasible due to Covid-19 with its associated lock-down and online working.

This section detailed the application of the research design selected for this study. The following section summarises this chapter.

3.4 SUMMARY

This chapter described and justified the chosen methods for this study and their application in line with the research aim and objectives. These chosen methods are summarised in section 3.2.11. Data collection and analysis follows an iterative process and constructivist approach as set out at the beginning of the chapter. Having described first five phases of thematic coding analysis, the following chapter reports the findings from thematic coding analysis and identifies dominant discourse coalitions which will then be used for discourse analysis in Chapter 5.

CHAPTER 4 MAKING SENSE OF TRANSITIONS OF GB'S ELECTRICITY SECTOR: A THEMATIC ANALYSIS

4.1 INTRODUCTION

This chapter presents a thematic analysis of data collected from interviewees on the transitions of GB's electricity sector to a low carbon future. Five main themes are identified:

(1) Changes of the sector in electricity generation, consumption and distribution (network)
(2) The timeframe and nature of change
(3) How stability of the sector is described and whether stability should be overcome
(4) The role of regulation and energy policy in transition
(5) The goals of transition to low carbon energy futures including decarbonisation and flexibility.

These themes reveal diverse assumptions of interviewees on how transitions may unfold. These assumptions are then used to group actors into different coalitions. This process forms a key part of discourse analysis and will be used to identify futures in Chapter 5. Therefore, at the end of this Chapter 4, some dominant energy discourse coalitions are set out.

4.2 CHANGE

Data collected from this study show that interviewees shared a view that the GB's electricity sector is changing. These changes fell into the categories of (1) Electricity generation, (2) Electricity consumption and (3) Electricity distribution (network).

4.2.1 Electricity generation

On the generation side, low carbon energy technologies are gradually replacing incumbent fossil fuel generators such as coal and gas plants. These low carbon technologies include various centralised forms of generation, such as biomass plants, offshore wind farms and nuclear power, as well as multiple decentralised installations, including onshore wind farms and PVs on industrial and residential buildings. However, the interviewees did not agree on what is the most significant technology. Biomass plants are argued to be developed in fairly high volume due to the "*move away from coal to coal biomass*" (I7 – Energy supplier). Similarly, due to the windy coastline of the UK, offshore wind is highlighted as a "*direction of travel*" in GBs future generation mix (I7 – Energy supplier). In terms of nuclear power, the majority of interviewees were ambivalent about its development. Some interviewees argued against nuclear power, one suggesting that there might be "…*a sort of collapse in the sort of idea of large centralised, particularly nuclear power.*" (I1 – Academia), whilst another suggesting that due to its inflexibility, it "…*just won't fit the rest of the system,*" (I16 – Government). In terms of decentralised generation, there is a consensus among interviewees about the further development of solar power but uncertainty about the development of onshore wind, particularly with the lack of government funding.

Several interviewees commented on how, with these new technologies, there is a significant increase in the number of actors involved in electricity generation, changing the way the electricity sector is managed. For example, an interviewee described,

> *"It was previously an industry where we have some large central generation plants. …that has changed over the past 5-10 years, now we have thousands of different types of power plants."* (I3 – Industry commentator)

According to this interviewee, the move from fossil fuels to multiple low carbon generation installations has meant that the system operator no longer manages a small number of large dispatchable power plants to meet the peak demand. Now, it manages multiple generators, some of which are non-dispatchable. These changes in generation creates challenges for the current system operator. The task of balancing supply and demand becomes increasingly difficult because the system is no longer able to turn on *quick start-up* power plants to meet peaks and troughs in demand.

Within generation, further innovation in low carbon technologies such as renewables are likely to be needed. Decentralised renewables such as onshore wind and solar has been linked with various storage devices. Large-scale storage batteries connecting to transmission grids are expected to develop to not only provide reliability for the system and accommodate the development of renewables but also connect to EVs charging points to facilitate the further uptake of EVs on the consumption side. These innovations may play a role in the transition of the sector to a low carbon future where a variety of innovations in the consumption side and network side are emerging.

4.2.2 Electricity consumption

This section explores the changes in electricity consumption, arising from energy efficiency and further uptake of EVs, as well as the changes in the role of consumers. As a result, many technological innovations and business model innovations are developed. They are described below.

4.2.2.1 Current changes

On the consumption side, interviewees noted that energy efficiency has been enhanced by power saving innovations. However, future uptake of electric vehicles (EVs) among households may off-set these reductions in household demand for electricity. Such increased demand may exceed the capacity of the grid at various times of the day. Interviewees highlighted that network constraints on distribution grids will be of particular concern here. As an interviewee from a network company argued,

> *"So what's happening with electric vehicles is that we will use all the capacity we'd built for 40, 50 years probably within 10, so that's what will happen and that's why electric vehicles at moment you say it's fine, yeah, connecting them isn't the problem. There will be a problem in the future because all of a sudden you know the industry, housing and stuff continue to grow, the capacity we have built in for that won't be there, it will have all been used by electric cars."* (I24 – Network company)

Interviewees commented on the efforts to address this concern through a number of trials that have been initiated to test the utility of various new technologies, such as battery storage or demand side flexibility, to help overcome network constraints. These trials have mainly been conducted by network companies, as data shown from comments of interviewees from academia and network companies. Some research has also been conducted by independent research institutions. For example, an interviewee referred to a research from Aurora to argue that the industry needs to "*implement electric vehicles in a flexible way*" to avoid unnecessary spend on infrastructure (I12 – Energy supplier).

Interviewees stated that changes on the consumption side may not only arise from the adoption of new technologies such as EVs and battery storage but also from changes in industry relations with consumers. Two opposing views emerged about consumers and their willingness to engage with the sector. These different views are further explored in section 4.2.2.2 below.

More consistently, most interviewees argued that consumers are likely to be considered by industry actors as more important than before. Interviewees suggested consumers may also potentially provide demand side flexibility to help the system operator balance the grid and/or help distribution network operators manage network constraints. With the development of PVs and battery storage, interviewees stated more and more consumers may become "*prosumers*" in futures, i.e. generators and consumers of electricity. Prosumers might be governed by community energy and/or local authorities which is not usual in GB's electricity sector. For example, an interviewee described a situation where a school generates their own electricity through solar panel and sells their unused electricity during school holidays. This arrangement might be managed by a local authority or a community energy (I9 – Network company). These changes are deemed as a process of democratisation according to some interviewees. Democratisation is defined as "*putting power in your and my hands as the end customers*" (I26 – Code administrator). Democratisation may challenge current practices in the sector which assumes passive consumers.

As consumers play a more important role in the sector, the industry will need to bring consumers to the fore and change their relationship with consumers, perhaps by conducting consumer-focussed trials to better understand them or develop innovations which focus on consumers. Interviewees suggested that consumer-focussed innovations can be disruptive because they re-develop the relationship between consumers and the industry. The following section looks at these innovations which interviewees termed consumer-centric innovations.

4.2.2.2 Consumer-centric innovations

Technological innovations are developing to enable domestic consumers to continue their daily routines and be delivered in such a way to help the sector overcome network challenges. For example, the further uptake of EVs among households with smart charging technology might meet consumer future demand for personal transport and help to balance the grid. As an interviewee described,

> *"If … the consumers don't need the car at all for the whole of the next day, they [the consumers] can respond to the charging rate, to market conditions at the time, etc. And so certainly, electric vehicle charging seemed to me that it will be the real focal point of consumers' flexibility."* (I7 – Energy supplier)

Similarly, a number of interviewees suggested the continued rollout of smart meters and smart home appliances offer opportunities for the industry to develop a better understanding of consumers and consequently formulate more suitable business models. Smart meters can also influence consumer behaviours as they make consumers aware of their energy use and charges in real time, or in other words, have "*a lot more visibility about what's going on [consumers' energy use]*" (I14 – Industry commentator). For example, households may restructure their activities to move to times of the day when the electricity charges are lower. Here, consumers are assumed to act rationally following economic incentives.

With interviewees who assumed that consumers hold economically rational behaviour, time-of-use tariff business model is developing alongside the further uptake of EVs and the continued roll out of smart meter. Electricity suppliers recognise the potential benefits of households with EVs and smart meters for network management and offer them variable electricity pricing for different times of the day. In one case, EVs time of day tariffs led to consumers/ EVs owners change their charging to "*out of peak*" (I18 – Energy supplier). Time of use tariff can potentially reduce energy consumption at peak times (usually between 4pm and 7pm). This reduction may assist the system and network operators to balance grids and overcome network constraints.

> *"So hope that when we have smart meters and their roll out is completed, they [consumers] will be either more interested or there will be sort of tools so that other people can offer them [consumers] something in exchange for doing that job for them"* (I3 – Industry commentator)

This time-of-use tariff model is facilitated not only by EVs and smart meter technologies but also by apps on smart phones which allows consumers to easily access their electricity use data and charges (I18 – Energy supplier). These apps can also be linked to smart home appliances such as smart thermostats which enable consumers to operate the smart home appliances remotely. Consumers in this case have the ability to switch appliances on and off to reduce their energy bills and also manage their home effectively in the future. As an interviewee anticipated, "*It [Smart home] will just be the easiest thing to do for your [consumers'] everyday life",* (I23 – Network company). Hence, EVs, smart meters and smart home technologies will create benefits for system operators, DNOs, energy suppliers, consumers or in other words, for the whole industry.

Conversely, some interviewees did not agree that consumers are actively engaging in their energy consumption and changing their behaviour as a result of economic incentives, e.g. one interviewee argued,

> *"the price of our tea is approximately the same probably or more than you've paid all day for the electricity in your house …he'll [a consumer will] spend 3.20 on a latte and not think about it, and then he'll [this consumer will] sit down and say my electricity bills too much. Right, really?"* (I14 – Industry commentator)

Interviewees suggested that a future response to such consumer behaviour can be that companies (energy service companies) not only offer energy services but also extend into multiple areas of consumer homes such as domestic heat, entertainment, transport and broadband to create "*a bundling of products together with services*" (I2 – Academia). Such business models are considered as consumer-centric, in the sense that they provide consumers with choices and convenience. As an interviewee described,

> *"I would like my house between 18 and 21 degree in these times of the day, it is up to you [energy service company] of how you deliver it"* (I2 – Academia)

Another suggested approach to delivery of such consumer-centric business models may be in the penetration of many "*consortia*" which supply consumers with "*electricity and gas and telecom and water*" and "*take away your [consumers'] waste and arrange your [consumers] baby sister*" (I3 – Industry commentator with Investor perspective). These consortia business models are different from energy service companies described above. While a consumer can only be supplied with electricity from one energy service company, a consumer is able to buy electricity from many different consortia. These consortia may potentially offer consumers many products and electricity as a by-product. In return, they may have control over consumers' home equipment such as fridge, washing machine, i.e. consumers demand side flexibility. For example, they may be able to remotely adjust consumers' fridges power in response to system's needs. Consumers may have an energy consortium for their food, another energy consortium for their electric cars and so on. This energy consortium model is similar to what is happening in the food industry where only some people "*go to the bread shop to buy bread*" while the majority of them "*buy that [bread] from the supermarket while they buy everything else*" (I3 – Investor perspective). These consortia are expected to exist alongside some traditional energy suppliers. Here, the future requires significant changes in market design because currently, consumers are only allowed to have one energy supplier. Similar to the energy service company model, consortia offer consumers with convenience and as such, are deemed to be consumer centric.

The business model innovations of energy service companies and consortia may also potentially change the links between consumers and other parts of the sector such as energy suppliers and network. The links with energy suppliers will change because consumers may receive bills directly from these new business models, rather than their energy suppliers. The links with network changes because consumers can participate in demand side flexibility to help resolve network issues, although indirectly by authorising energy service companies or consortia to manage their demand.

However, although technological innovations and business model innovations can potentially support demand side flexibility, the network is unable to utilise the advantages of demand side flexibility without the further development of innovations in networks. The following section looks at network innovations and their implications.

4.2.3 Electricity distribution (Network)

Currently, electricity generation and consumption are tied together via wholesale and retail markets. In the wholesale market, generators sell electricity to suppliers. In the retail market, suppliers sell electricity to consumers, e.g. households. Both markets are currently dominated by a few industry actors whose firms are vertically integrated. Often, generators, suppliers and even distributors are parts of one organisation. Generators can sell electricity via bilateral contracts to parts of their business that supply electricity. Interviewees stated that such contractual arrangements are reducing market liquidity. As an interviewee with expertise in regulation identified,

> *"…there is very little trading that isn't bilateral in one way or the other…we lost the ability to sort out things by prices in the whole sale market… we don't really have a liquid market where we can sort this stuff [system operator system balancing] out in an open and transparent way."* (I2 – Regulator)

This argument highlighted the issues with network balancing and the role of market and market liquidity in the current electricity sector.

A number of interviewees with a network perspective argued that the development of smart grids will be the most important innovation on the network side. Smart grids allow the system operator and DNOs to visualise low voltage level activities. An interviewee described that with smart grid, network companies might be able to identify in which area they "*need additional capacity*" and "*go to the market*" for "*flexible solutions*" (I19 – Network company). Similarly, another interviewee also highlighted that without smart grids, traditional network reinforcement was an easier option.

> *"…they [DNOs] don't know enough about their networks to buy flexibility …if we [the GB] have a smart grid, and then it would work, because …we say that we have flexibility in [a location] or whatever that might be. At the moment, they [DNOs] don't know that, so the easiest thing to do is just to do reinforcement"* (I4 – Distributed asset business).

Smart grids help the system operators and DNOs to not only make better decisions about which part of the network may benefit from demand side flexibility, but also to have vision of where demand side flexibility may be available. This would assist network companies to buy energy flexibility solutions from the market to balance grids and overcome local network constraints. An interviewee argued that smart grids will help "*optimise that [infrastructures] investment cost*" and ultimately "*reduce consumer bills*" (I19 – Network company). With smart grids' potential to lowest cost in helping DNOs to overcome network constraints and the system operator to resolve future grid challenges, smart grids are likely to support the development of low carbon sources and accommodate the uptake of EVs. Here, smart grids can potentially change the relationship between generation, network and consumption sub-systems.

Realising the benefits of demand side flexibility, both DNOs and other market players including technological new entrants are developing platforms for flexibility, so-called (1) flexibility platforms and (2) technology platform. For DNOs, flexibility platforms are where they can advertise opportunities to participate for whoever can provide DNOs with demand side flexibility. For new entrants, a technology platform can be an opportunity for a number of players to compete and supply flexibility for not only DNOs but also whoever needs flexibility. Flexibility platforms only provide flexibility for DNOs while the technology platform offers flexibility for a wider range of actors. These different types of platforms are looked at below.

The flexibility providers, called '*energy service provider'* by DNOs, can aggregate flexibility from consumers and offer it to DNOs via their flexibility platforms. Such platforms and associated demand side flexibility are likely to change the relationship between DNOs and their consumers and indeed with other actors in the market. Instead of having direct control over their networks, DNOs move toward a relationship model where their operations may be based on the contracts between DNOs and providers of flexibility.

> *"…that means when you depend on energy flexibility, if you start to move towards depending on the external agencies and companies on agreements with your customers, your major commercial customers or working through aggregators and intermediaries, you have less direct control and I think the challenge is that the company is actually used to having direct control rather than relationships"* (I1 – Academia)

On the other hand, an interviewee argued that a potentially disruptive innovation is the technology platform which creates real-time markets for "*different sources of energy flexibility and different users of energy flexibility*" (I27 – Aggregator). Therefore, flexibility may not only be useful to DNOs but also for other actors that require flexibility. By allowing a number of users who have or need flexibility to participate regardless of their type of organisation, such technology platform can potentially blur the conventional boundary between generation, network and consumption.

Another innovation which potentially changes the boundary between traditional sub-systems is transmission grid level battery storage (see section 4.2.1). This battery storage is connected to both transmission grids, to help system operators with balancing the grids, and EVs charging points to reduce EVs driver range anxiety, as an interviewee argued,

> *"[the UK has] a potentially unstable system, so we see the use of storage …we see the transition of fossil fuels to electric vehicles as a further impact on the grid, and so by marrying the two [storage and EVs], we have more control but we also have access to much larger volumes of power by going to the transmission system. So it really is that symbiotic relationship between the cars and the batteries, but access to bigger power than has been available before from distribution connection"* (I21 – Investor).

Battery storage can potentially provide a large volume of power for EVs charging points due to being connected to large-scale generation via transmission grids. Battery storage at transmission grid can become intermediates for system balancing and EVs owners; thus, change the relationship between conventional network and consumption sub-systems.

4.2.4 Summary

In summary, this section highlighted some changes in generation, consumption and network of the sector. Among them, the most noticeable changes are in the mix of generation from fossil fuel to renewables, the increase in the number of actors, the adoption of new technologies in consumption side such as EVs or battery storage and the changing role of consumers. These changes bring about associated issues in the sector, such as network balancing and grid constraints management. Some trials and research were noticed to further understand the implications of these issues and to develop innovations.

Innovations seem to play a key role in responding to these issues. Renewables and battery storage are likely to be further adopted on the generation side. The consumption side sees the development of EVs, smart home technologies and business models around these technologies, such as time of use tariff and energy service company models. On the network side, smart grids and platforms to offer flexibility are likely to dominate. Multiple innovations are likely to develop and supporting each other. For example, the development of time-of-use tariffs are likely to be alongside the further uptake of EVs, smart meters and smart home technologies.

Moreover, innovations including EVs, energy service companies, smart grids, platforms for flexibility and transmission grid-battery storage connecting with EVs charging model not only influence a part of the sector where they are situated but also potentially transform the traditional linkages between various parts of the sector as described above. Such innovations constitute architectural innovation that restructures the sector.

Furthermore, innovations in the future are likely to focus on consumer-centric innovations and include not only technologies such as EVs and smart appliances in home but also business model innovations such as energy service company or consortia models. This focus is in line with the increasingly important role of consumers in the sector.

This section also noticed contradictory views of interviewees in terms of consumers. While some interviewees argued that consumers will continue to be passive and not engage in the sector, others believed that consumers would become more engaged, moving away from conventional imagined passive consumers. However, interviewees’ perspectives in terms of consumers’ engagement are diverse. Consumers might be more active and become “prosumers” in the future, or change their behaviour rationally following economic incentives such as with the example of the time-of-use tariff model, or engage due to the choices and convenience they have in the example of energy service company.

These innovations which are multiple, architectural and consumer-centric and the changing role of consumers can potentially change the structure of the sector and thus stimulate and enable transitions to a low carbon future. The following section looks at the timeframe and nature of these changes.

4.3 TIMEFRAME AND NATURE OF CHANGE

Although interviewees share an agreement about some potential innovations in the future, there is no consistent view of when these will become mainstream. In terms of smart meters, an interviewee was pessimistic about their roll-out, “*now it is the middle of 2018, … we are nowhere near getting the roll out of smart meter to any level of density whatsoever*” (I4 – Distributed asset business). Regardless of this opinion, the roll out of smart meters is expected to be completed by 2022 by an industry commentator (I20) while an incumbent energy supplier anticipated the completion in 10 years, 2028 (I7). These various opinions on a timeframe of an innovation is similar to the further uptake of EVs. An interviewee argued that EVs are designed to suit personal needs which may not suit consumers who usually commute long-distances. Here, this interviewee expected the number of EVs will increase considerably by 2021 but may not outstrip the number of hybrid cars. Conversely, another interviewee anticipated that EVs are going to become mainstream in “*5 years’ time*” (2021) which is “*the car cycle*” (I15 – Network company). Regardless of timescale, some interviewees agreed that the EVs will become the main personal transportation (I5 – Industry commentator, I17 – Government) before 2040. This is the previous date of government ban on the sales of new conventional petrol and diesel vehicles (BEIS, 2017). This date has recently been moved forward to 2030 (DfT and BEIS, 2020).

Interviewees also hold diverse views about the timeframes for transition. For example, a number of interviewees argued that there may be more rapid changes in retail than in network infrastructure. The logic behind this assertion appears to be that infrastructure requires large investments and hence, takes longer to change. As such, interviewees from network companies usually had in mind longer timeframes for transition than others. For them, the 2050 timeframe was a reasonable timeframe for changing the network while interviewees from other parts of the sector tended to focus upon 5 – 10-year timeframe, i.e. by 2030. The 2030 timeframe ensured enough time for the new regulatory framework to come into force. For interviewees from network companies, the 2050 timeframe allowed sufficient time for development, testing and commercialisation of network technologies. As an interviewee with expertise on both network and retail argued,

> *Electricity utility infrastructure is the one you don't spend a lot of money on. So, in reality, the timeframe for it is longer than people sometimes expect"* (I15 – Network company)

A number of interviewees did not elude to an exact timeframe because according to them, time was a big unknown, sharing a consensus that there are many influencing factors which lead to uncertainty. Interviewees suggested that the timeframe can be influenced by disruptive events occurring on the supply or demand side. For example, the awareness of the industrial actors that building more nuclear power is the only option for future, but unaffordable or the increase in the number of EVs may create big impact on the system and "*force some new thinking to come through in terms of the system for flexible management"* (I1 – Academia). Rapid changes may also be achieved with consumers' support, as an interviewee identified,

> *"…once these innovations grip the consumer imagination, it's actually quite surprising how things can take off and the business models therefore have to change"* (I5 – Industry commentator).

With innovations being influenced by different factors, interviewees recognised that changes in the sector occurred at specific times and in specific spaces, i.e. they are shaped by context.

In the context of the electricity sector, by looking at the internal issues of the sector and the development of innovations to resolve these, interviewees assumed that the sector would go through an unstable period. However, there is a tendency to *prevent* instability because electricity is so vital, i.e. maintain security of supply. Interviewees advocated incremental rather than radical changes. The following sector looks at how interviewees discuss stability.

4.4 STABILITY

Stability and change is the core issue of transitions research (Köhler *et al.*, 2019). While the previous section discussed changes in the sector, this section focuses on stability. Some interviewees argued that stability is essential while others noted that maintaining stability can give rise to barriers to transitions.

4.4.1 Stability is essential

A number of interviewees argued that stability is essential for the sector to operate, even when it is in transition. Stability is founded upon the "*fundamental physics*" of the electricity network (I13 – Government and I23 – Network company). Such "*fundamental physics*" requires electricity grids and networks supply and demand to remain in balance at all times. Otherwise, electricity supply will be disrupted which will affect, for example, households and commerce. Currently, the system operator oversees the network to ensure the reliability of electricity supply to households and industry. The reliability of electricity supply may be challenged by an increase in non-dispatchable renewables and reductions in system inertia (I5 – Industry commentator and I11 – Energy supplier). An interviewee explained that "*System inertia is generally given by spinning turbines*" of fossil fuel power stations (I11 – Energy supplier). In case a fossil fuel power station stops working, these turbines keep spinning to "*keep the grid frequency stable*" and ensure system reliability (I5 – Industry commentator). Although the sector is changing, reliability needs to be maintained. Transitions can only occur in such conditions. As an interviewee from the public sector noted,

> *"I want National Grid to be there, keeping things working because the stuff that goes on in the grid edge [from consumers' side) doesn't care about the physics really, somebody needs to watch the physics, so that to me is one thing that needs to be stable as there is somewhere somebody needs to be assuring the technical integrity of what's going on"* (I13 – Government).

4.4.2 Stability is a barrier

In contrast, several interviewees noted that obdurate elements need to be removed for low-carbon innovations to develop in particular and for the sector to transition in general. Interviewees identified various barriers which prevent the sector from changing, including (1) Technological barriers, (2) Financial barriers, (3) Organisational cultural barriers, (4) Consumer barriers, (5) Informational barriers, and (6) Market design barriers. This section considers these barriers and their role in transition to a low-carbon electricity sector.

4.4.2.1 Technological barriers

Although many innovations have been developing to resolve the sector's internal issues such as those highlighted in section 4.1 above, interviewees noted some limitations of the technologies upon which these innovations are based, e.g. batteries in EVs. EVs can potentially support the development of demand side flexibility if consumers using EVs change their demand patterns to meet system needs. However, according to some industry commentators, by completing short-discharge cycles, EV owners may face the risk of reducing their battery life and ultimately may need to replace the battery in their vehicles sooner than usual, which is likely to be expensive. One interviewee drew upon the example of the battery in an Apple I-Phone to suggest how battery life is reduced,

> *"You start off an iPhone, you can run two or three days, can't you? Pretty quickly within the first year you have to recharge that every single day, and sometimes twice a day, don't you?"* (I5 – Industry commentator)

Here, interviewees argued that one of the barriers for the development of demand side flexibility may arise from the limitations in battery technology and cost of replacement. In the future, by having batteries which are better suited to short-discharge cycles, it was assumed that consumers would act rationally and charge and discharge EVs in response to changes in electricity prices. As an industry commentator described, the situation with battery technology is uncertain,

> *"Greatest thing that somebody can offer you is an intelligent way of using that [batteries in electric vehicles] for additional purposes which is effectively to soak up energy when it's cheap and then deliver it back to the… my home when it's expensive, providing that it doesn't impact my ability to drive the car, that sounds great. But has there been any research to look at the impact of short dip discharge on a vehicle battery you know?"* (I5 – Industry commentator)

Similarly, the absence of new technologies for the system operator to procure Black Start is considered by some interviewees as a key barrier for sector transition, especially in generation. Black Start is the service that the system operator buys to recover the electricity system in case of black-outs. Currently, fossil fuel power plants such as gas or coal are the only technology that can offer the system operator this service due to their ability to provide system inertia, as an interviewee identified,

> *"…Now we can do that [Black Start] with gas fire power stations and coal-fired power stations, it's not so it's not very difficult. It basically comes down to large spinning bits of metal and then you plug everything in and you jump it off this big spinning bit of metal."* (I17 – Government).

Transitioning to a future without gas power plants thus requires the development of new technologies which can help provide this Black Start service. These technologies do not currently exist "*or at least we [the sector or more specifically the system operator] don't know how to do it yet*" (I17 – Government).

However, new entrants in the sector argued that technological development will not be a barrier to transition as demonstrated by the development of disruptive technologies in other sectors such as smart phones in telecommunication. For example, no one thought of using smart phones as they were expensive while today, almost everybody carries smart phones.

> *"… the rate of innovation and the pace of change in a technology sector that doesn't rely on hardware and manufacturing but relies on software and innovation happens unbelievably exponentially quickly … cost of the kit [smart phone] coming down hugely to the point where today you can get you know a $15 smartphone"* (I18 – Energy supplier)

For this interviewee, the cost of technology, rather than the technical aspects of technology itself matters. The cost of technology is considered in detail in the following section.

4.4.2.2 Financial barriers

There are three main financial barriers as identified by interviewees (1) Cost of technology, (2) Financial incentives and (3) Subsidy.

4.4.2.2.1 Cost of technology

As mentioned in the previous section, interviewees noted that batteries are expensive. Having to spend significant amounts of money to replace EV batteries may deter consumers from participating in vehicle to grid storage (demand side flexibility). As an interviewee highlighted,

> *"…my most anxious point about buying a fully electric car is how long the battery will last and how much it is going to cost me to replace it you know… I've just spent you know thirty thousand pounds on a Nissan electric car and I find I'm facing a very significant bill to replace the battery and Nissan turned out and said it was because you did the short discharge cycles"* (I5 – Industry commentator).

The cost of replacing EV batteries is deemed to be a financial barrier to demand side flexibility. Some interviewees felt the initial cost of new technology could be a barrier because "*there's lack of economies of scale*" (I10 – Energy supplier).

However, the majority of interviewees believe there will be a significant reduction in the cost of technology. For example, in the case of smart technologies in home, they are "still expensive" now as noted by an interviewee but will reduce in three and four years (I23 – Network company). Another interviewee also highlighted,

"…costs are coming down sufficiently fast, technology to become sufficiently powerful" (I27 – Aggregator).

4.4.2.2.2 Financial incentives

Interviewees who are industry commentators and working in network firms stated that the financial benefits of participating in demand side flexibility are often insufficient to motivate consumers to engage in such schemes. Seen in this way, finance may act as a barrier to demand side flexibility. According to these interviewees, consumers are unlikely to help balance grids or DNOs to manage network constraints if only a very small amount of money is offered, e.g., 30p per day (I4 – Distributed asset business), even less than the amount they spend for a cup of coffee at a coffee shop (I14 – Industry commentator). Similarly, an interviewee used evidence from research to argue for the low cost-savings of consumers in participating in demand side flexibility, which arguably is unable to incentivise consumers to participate,

> *"…Vivid economics, they did the report with the WWF ... So, let's say it's [savings from demand side flexibility is] 100 pounds a year, it's two pounds a week, … as a customer, am I bothered by two pounds a week? Probably not. I would probably rather just plug my car in and know it's charged and ready for me in case of emergency"* (I22 – Trade association).

In these cases, interviewees assumed that consumers act rationally following financial incentives. However, interviewees from a range of organisational perspectives such as trade association, electricity new entrant supplier, consultant company disagree with the assumption that consumers act rationally. According to them, consumers do not act economically-rationally even when they are financially incentivised to behave in a particular way. They noted that consumers charge their EVs or phones as the need arises, rather than due to lower electricity bill emerging when the electricity system needs to overcome network constraints or be in balance. Reducing electricity bills is not consumers' concern because the demand for electricity is taken for granted regardless of electricity price, as in interviewee noted,

> *"…fundamentally energy prices are high but people are willing to pay"* (I10 – Energy supplier).

4.4.2.2.3 Subsidy

Interviewees discussed whether subsidy is another financial barrier to innovation. Some interviewees argued that subsidy assists the development of local low carbon technologies. One interviewee from the investor community argued that the government feed-in-tariff programme (a form of subsidy) brought about huge increases in PV adoption among households.

> *"…when they [consumers] saw what was being offered for solar PVs [feed-in-tariff], they would see a good return on their investment, so they invested in that."* (I3 – Industry commentator)

On the other hand, interviewees from both the industry and academia noted that subsidies may stifle innovation rather than stimulate it. An industry commentator did not totally deny the benefits of subsidising innovations, especially in the case of the Feed-in-tariff but suggested that subsidy should only be applied at the beginning of innovation diffusion and should not be provided on an on-going basis. This would avoid a situation in which a particular trajectory of innovations is established, and the industry fails to develop new ones. Moreover, subsidies stifle innovation in the sense that the industry is not going to innovate without receiving any price incentives from the government. An interviewee described the current situation in the sector as '*awaiting to be subsidised before making any effort to build power plants or to innovate*' (I2 – Academia with regulatory perspective). Some interviewees argued that this has brought about an illiquid electricity market which should be avoided.

Both proponents and opponents of subsidies apply economic theory to understanding sector transition. They again assume that the industry behaves rationally following price incentives. These interviewees are likely to pay less attention to other aspects such as organisational culture and consumers which may impact transitions. The following sections look at organisational cultural and consumer barriers.

4.4.2.3 Organisational cultural barriers

Interviewees highlighted that the electricity sector is experiencing some barriers relating to cultural aspects of the industry such as the traditional mindset and established skill sets.

4.4.2.3.1 Traditional mindset

Interviewees from both the electricity sector and incumbents of another sector moving into electricity sector argued that a key constraint to transition is a centralisation mindset. This mindset is adopted by sector incumbents who interviewees suggested are "naysayers" of change,

> *"I think that fear [of a decentralised flexible market] is quite often driven by incumbents, who are basically saying oh well it won't work, the kind of naysayers of the future. Oh you can't do that, you can't do that and that kind of very low level kind of undermining of this future vision is there because to a certain extent, there are very few people out there going Yeah we can do a flexible market."* (I12 – Energy supplier)

This centralisation mindset also usually leads to the market design and framework supporting centralised assets rather than decentralised innovations. Several innovations which can potentially bring about transition in the sector such as storage or flexibility are at a disadvantage in the current market design. As long as this organisational cultural barrier remains, it is difficult for the sector to transition. Barriers associated with market design is further explored in the section 4.4.2.6 – Market design barriers.

4.4.2.3.2 Skill sets

This traditional mindset partly arises as a result of the absence of appropriate skill sets for the future. Interviewees who are industry commentators, new entrants and DNOs noted that the sector is dominated by traditional engineers while in the future, skills related to data analysis, developing relationship with consumers, project management, IT and software will be needed or more specifically, "*they need to have more ability to look at more data*" (I20 – Industry commentator). Organisational leaders may have these engineering focussed skill sets, especially incumbents. As organisational leaders, they might stifle innovation from within their organisations. However, it does not mean that innovations are not developed by incumbents, deficiencies in skill sets may be a challenge for innovation but not an insurmountable one. Interviewees highlighted two opposing ways of developing future innovations in sector incumbents. Incumbents may develop innovations internally or they may buy innovations from new entrants and integrate these innovations into organisational operations. Either may face cultural challenges, e.g. from sector leaders. An interviewee from an incumbent energy supplier described the cultural situation in his organisation as below,

> *"Lots of people who are in maturing roles have got skill sets that may no longer be relevant to the future, and therefore when someone is challenged that their skill sets could become outdated, then they would reject change. And so the change character impacted by people is when we come up with something that's a disruptor, it starts off being considered ludicrous and then it moves to being considered dangerous, then it moves to being considered obvious and if we get stuck in the ludicrous and dangerous stage, then we stop putting all of our efforts into effective change but instead, we put our efforts into overcoming barriers."* (I11 – Incumbent energy supplier)

An interviewee who does not want to be quoted stated that skill sets needed in the future might not only be absent in sector incumbents but also in Ofgem, the current regulatory body. This interviewee argued that Ofgem may not have the skills to design an appropriate market(s) when the UK exits the European Union. Currently, Ofgem's decisions on any change in market design is in accordance with European regulators such as the Agency for the Cooperation of European Regulators (ACER). Section 4.4.1 considers the regulatory structure further.

4.4.2.4 Consumer barriers

Consumers might act as barriers for the transitions of the sector. Interviewees agreed that the industry lacks consumer trust and it will create a massive problem for the sector when engaging consumers in transition. An interviewee referred to the Competitive and Markets Authority (CMA) report and argued that low engagement of consumers in the industry is "*part of the trust thing*" because "*You [consumers] realise you're paying three hundred pounds more for nothing different, for your gas and electricity provides"* (I5 – Industry commentator).

There is no consensus among interviewees about whom consumers may or may not trust. Industry commentators and sector new entrants argued that consumers do not trust incumbent energy suppliers because it is alleged that they have taken advantage of consumers and pursued large profits. Conversely, incumbents noted that consumers are unlikely to trust new entrants because they may not be reliable, with some going out of business. Seeing consumer trust as a barrier to transition, the sector is looking to build better relationships with consumers. However, such efforts are likely to be hampered by a paucity of consumer data in the sector. Informational barriers are considered next.

4.4.2.5 Informational barriers

As mentioned in section 4.3.2.3.2, skills related to data analysis might be needed in the future. Interviewees argued that the availability of data and access to data are two informational barriers to transition. Data needed for transition includes consumer and network data. Interviewees from both suppliers and network firms noted that consumers usage is currently understood in terms of profile classes. A profile class represents "*the pattern of electricity usage for a customer segment of the electricity supply market*" (Elexon, 2018). The sector also treats consumers according to their profile classes, not their real-time energy use. This limits the development of demand side flexibility from residential households. As an interviewee from a new entrant energy supplier argued,

> *"… the main industry is based on the profile class-1, where there's a peak in the morning and there's a peak in the evening and every customer is treated exactly on this profile, where as you will see in the reality, we are seeing reality is that each home is different and trying to understand and trying to capture data to understand how people actually use their home energy is the place you have to start."* (I10 - new entrant energy supplier)

In order to overcome this informational barrier, many options were suggested by interviewees. First, some technologies to collect real-time data should be used such as smart meters, battery storage and via home appliances. Second, regulation needs to change so as to allow certain data to be accessed, for example in the case of smart meters. Smart meter data are "*in theory*" accessible by a regulated Smart Data Communications Company (DCC) but "*it looks a little bit exclusive about who can access it [data]"* (I2 – Regulatory perspective). Removing informational barriers may allow the sector to better understand consumers and develop demand side flexibility.

Interviewees identified a lack of data in the relationship between transmission grids and distribution networks. This data gap may increase costs of managing network issues, i.e. *"paying for things twice*" (I2 – Academia). For example, an ancillary service requested by the system operator to solve an issue on a transmission grid may cause a distribution grid constraint. The system operator is then required to request a second ancillary service to resolve this distribution grid constraint which may in turn cancel out the first service. In such instances, both services are paid for. This informational barrier reflects a lack of transparency in the market design. How interviewees discuss market design is considered below.

4.4.2.6 Market design barriers

Interviewees argued that the design of the market can directly impact innovation. For example, battery storage can potentially support different parts of the sector at the same time. An organisation developing batteries can offer the system operator balancing and ancillary services, DNOs to reduce network constraints, support electricity suppliers in balancing their portfolio and so on. However, such value stacking is prohibited within current market arrangements. For example, the market rules specify that actors may develop specific, exclusive contracts. Here, once a firm offering battery storage is exclusively contracted with the system operator in the balancing and ancillary market, it cannot access other markets. Battery storage is therefore unable to "*stack up"* to its full value in the sector, as noted by an interviewee with a regulatory expertise.

> *"If you take an example of something like the battery, it has got limited ability to access the value it could represent in the system. So, at the moment, the business case for commercial battery is together contracting to National Grid for frequency response, it is a short term contract, it is like 2 or 4 years, not too long, and that is basically the only thing you can raise finance against, that limits your certainty of future revenue. But actually, the value of the battery is multiple… But you cannot stack up all the values in order to make a good business case because it is very hard to get into different markets. So, there is the market architecture problem"* (I2 – Regulatory perspective)

This interviewee also argued that this market design problem is deemed to be a result of "*regulatory challenges*" (I2 – Regulatory perspective) or in other words, is created by current regulation which is looked at in section 4.5.1. In futures, an interviewee expected that battery storage can participate in "*wholesale market arbitrage which would be much more interesting*" (I11 – Energy supplier). Price arbitrage refers to the price differential between "*buying power when it [price] is cheap, sticking it [power] into your battery and selling power when it [price] is expensive*" (I8 – Network company). Such price arbitrage creates a liquid market which are advocated by many interviewees as argued by an industry commentator with a wholesale market perspective. Seen in this way, the market mechanism plays an important role in the future. As a consequence, removing any barriers for the market to work well is essential.

Interviewees also noted that the operation of the electricity sector is administered by a large number of licences and industrial codes which are complex. The "*complexity*" of these licences and industrial codes means it is potentially difficult for new entrants to penetrate the electricity sector/ market (I5 – Industry commentator). The current market design here can be considered as a barrier to transition.

On the other hand, it was stated that simply removing barriers is unlikely to automatically lead to transition as there are likely to be further complications created. For example, for the development of the consortia model discussed in section 4.1.2.2, consumers need to be allowed to have more than one supplier, which then requires the regulator to amend its current market design. However, non-traditional energy suppliers might be unable to deliver government schemes which is the task of current traditional suppliers. Consumers may also be unaware of dispute mechanism to whom their complaints may be addressed. As described by an interviewee with expertise about the electricity market,

> *"… who's delivering all those government schemes that we spoke about such as eco and warm home discount? I mean, is Samsung responsible also for the installing energy efficiency measures because they were also selling you electricity for your TV? I have no idea but I doubt Samsung want to get involved in delivering energy efficiency measures."* (I22 – Electricity market).

In summary, this section highlighted many barriers to change. These barriers arise not only from technology but also from non-technological sources such as finance, culture, information and the market design. By highlighting different barriers to change, especially technological barriers and financial barriers, interviewees assume that actors in the sector, including consumers, act rationally following economic incentives. Interestingly, for many interviewees, transition is assumed to be a linear process of identifying barriers and removing barriers. This will be further discussed in Chapter

6. Nevertheless, transition may be more complex than just a linear process set out above. Multiple barriers seem to exist rather than a single barrier. Besides, removing a barrier may lead to other issues for the sector to resolve. Transition may come about via changes in regulation and policy. The following section discusses regulation and policy which may impact transitions in the sector.

4.5 REGULATION AND POLICY

Interviewees argued that regulation prevents the sector from addressing various barriers highlighted in sections 4.3.2.3.2 (regulator skills), 4.3.2.5 (data access regulation) and 4.3.2.6 (market design issues created from regulation). Firstly, regulation was thought to prevent new entrants from entering the electricity market, mainly because the current market design and arrangements limit the value new entrants can bring. Secondly, interviewees stated that the market has a number of complex codes and licences which are not easy for new entrants to understand (I5 – Regulation perspective). Thirdly, it was argued that the regulator does not have sufficient skills to design an appropriate market for a low carbon future. Finally, interviewees also noted that the regulator was not transparent about data access. Here, regulation is assumed to be a barrier to transition and needs to be reviewed. However, transition may not arise from simply removing regulatory barriers or adjusting market arrangements but from changing the whole regulatory structure. Transition may need a long-term goal to be embodied in a stable policy framework. This section considers regulation and policy, and their roles in transition.

4.5.1 Regulatory structure

Interviewees stated that the development of the electricity sector is constrained by the regulatory structure. Within the current regulatory structure, interviewees noted that the three functions of the electricity sector which are generation, network and consumption are treated as separate entities and managed as such. For example, generators are not allowed to take part in the operation of the network or consumption. This separation may be inappropriate for the development of innovation which may span generation, network and consumption such as transmission grid's battery storage or demand side flexibility as highlighted in section 4.1.3. Here, transitions to a low carbon future may require the boundaries between the three separate functions to be blurred. In other words, transitions require a change of regulatory structure and a move to systemic management.

> *"What you've got is a regulatory system which was developed around a particular model which separated those functions [generation, network and consumption]. Flexible energy system requires blurring the boundaries between those functions. And so, regulation makes*

it difficult to move towards, so question in my mind is what will be the regulatory structure which actually works for a flexible and dispersed generating electricity system". (I1 – Academia)

Changing the current regulatory structure is not easy because the electricity sector is too important to be left unstable in transitions as mentioned in section 4.4.1. The change in regulatory structure may challenge the reliability of supply which is unacceptable in the sector. On the other hand, interviewees argued that changes need to come from policy, rather than regulatory structure because the sector is dominated by "*lots of big energy companies [which] are separately [and privately] owned*" (I11 – Energy supplier) which may resist changes or change in different ways that regulation may not foresee and be unable to manage. The following section discusses energy policy.

4.5.2 Energy policy

Energy policy has an important role in the sector as argued by the majority of interviewees. Energy policy together with regulation can create an environment for innovation to flourish and for changes to accelerate. Innovators need certainty from policy and regulation in order to manage the risks associated with innovation. For example, in the case of battery storage which is highlighted in section 4.4.2.6, an interviewee argued that if there are more and more battery storage are built, they will reach "*flexibility saturation*" (I8 – Network company). It is the point where price differential or price arbitrage, from buying electricity at cheap price to storage in a battery and selling electricity at higher price, is going to close. Here, investors in battery storage will face the risk of uncertain revenue stream in the future. In this instance, a "*capacity market*" from energy policy and regulation to ensure these battery storage investors secure stable revenue stream in futures might be needed. Interviewees also argued that the government and regulation are "*sources to funding for various projects"* (I9 – Network company) including research and demonstration projects. Research project allows "*learnings to be taken*" (I9 – Network company) while market demonstration projects are "*real evidence*" for the government and regulator to "*bring pressure to bear on the industry to get them act together*" (I4 – Distributed asset business). These projects, as a consequence, are arguably able to stimulate innovations.

One interviewee from a network company stated that energy policy in the UK does not appear to have any long-term target which is needed to steer a transition to a low carbon future. This interviewee also argued that the government needs to provide *direction* in the long-term for the industry and also needs to take into account recommendations from scientific research. For example, the National Infrastructure Commission (2016) which provided good evidence and valuable recommendations of how the grids should be strategically upgraded. However, this interviewee criticised that the government did not take into account this report's recommendations and expected a governmental change. As such, it is assumed that transitions of the sector require an energy policy. Here, energy policy may or may not be written down (e.g. a signal from the government).

On the other hand, some interviewees (especially those from the investor community) noted that the sector performs well in an uncertain environment, i.e. does not need the certainty created from policy and regulation. For example, the price of solar PVs reduced very quickly while government feed-in-tariff reduced gradually. The regulator and government often lag behind sector development (I3 – Industry commentator). Moreover, in the case of the Capacity Market which has been suspended, an interviewee noted that it was put on hold without any notice which demonstrated regulatory and policy uncertainty. Actors learned to get used to and work under condition of uncertainty (I21 – Investor).

Change in regulatory structures necessary for transition to occur may or may not require energy policy. Energy policy such as decarbonisation and flexibility is further discussed in the following section - Goals of transitions.

4.6 GOALS OF TRANSITION

Transition to a different electricity system requires policy makers to set a long-term target as suggested in section 4.4.2 with a predefined goal (e.g. low carbon) to set direction and guide activities. This section discusses the two main potential goals of GB's electricity sector transition: (1) Decarbonisation and (2) Flexibility.

4.6.1 Decarbonisation

The need to decarbonise has profound implications for GB's electricity sector. Some interviewees argued that decarbonisation not only drives the change from fossil fuel to low carbon technologies but also motivates actors in the sector to invest in clean energy and to help resolve network problems arising from non-dispatchable low carbon generation technologies. Here, decarbonisation is deemed to be a transition goal.

Interviewees highlighted that the decarbonisation goal could also drive the UK economy: the government is able to develop a strategy which is both clean and economically driven. An interviewee also noted that it might be easy to miss the decarbonisation target if the industrial strategy prioritises economic growth at the expense of environmental issues. Having a predefined goal of decarbonisation is essential for forward planning.

> *"…you wouldn't have an industrial strategy that was going to drive decarbonisation, but you could have a decarbonisation strategy which is going to drive industrial growth"* (I13 – Government)

Interviewees argued that the government and regulator are able to ensure that the decarbonisation goal is achieved. Government sets the target for decarbonisation and the regulator interprets government policy and develops regulations accordingly. Via some market arrangements, such as Feed-in-tariff, Contract-for-Difference and Capacity Market, the government and regulator can implicitly identify certain technologies or "*pick winners*" (I22 – Energy supplier), that may assist in transitions to low-carbon futures. However, the government and the regulator often engender uncertainty in the sector, as argued by an interviewee in investor community (I21).

Although an interviewee noted that decarbonisation should be a transition goal, the government seems not to prioritise this in their decision-making processes. An energy supplier (I18) argued that the government and regulator prioritise consumer protection at the expense of decarbonisation. In other words, the government may prefer gas power plants over offshore wind due to the concern that decarbonisation activities may create a small increase in consumers' energy bills. However, this interviewee argued that such concern may be invalid as the cost of clean technology may come down over the long-term and offset any price differences. Moreover, the long-term gain of decarbonisation may far outweigh modest increases in consumers' bills at present. Therefore, decarbonisation should be brought to the fore in energy policy. This argument is noted below,

> *"I think the main thing is just to keep a real focus on putting decarbonisation at the heart of every single decision made by government. A lot of decisions were made by government because of a misguided understanding of what impact they might have on consumers and that's unhelpful sometimes …in fact what you know if you're looking further out to the future, what we need is cleaner, you know, not devastating climate change and frankly you know a technology curve that brings down the cost of the energy that has a marginal, that has a very low marginal cost."* (I18 –Energy supplier).

On the other hand, some interviewees seem to consider decarbonisation as a profound challenge faced by the sector, rather than a goal of transition. Because of decarbonisation and the binding carbon target that the UK commits to, the sector needs to change. Decarbonisation is hence an internal issue which forces the sector to change. The following section considers whether flexibility is a goal of the transition.

4.6.2 Energy flexibility

Some interviewees considered energy flexibility to be a goal of transition. Flexibility in this instance broadly means network capacity which is able to cope with large changes in electricity demand, especially from new loads related to the further uptake of EVs. According to these interviewees, the government and regulator need to take a long-term view of the network assets likely to be needed in the future as highlighted in section 4.4.2. An interviewee from a network company argued that future networks need to be built strategically with a pre-defined goal of network flexibility embodied in a long-term energy policy. Following such energy policy rationale means that networks are likely to attract more investment not only to expand them but to change the quality, e.g. to accommodate two-way flows that may be digitally mediated. Here, investment is assumed to be the result of rational choices made by investors in response to energy policy signals.

On the other hand, a number of interviewees thought of flexibility in terms of problems and solutions. The reduction of flexibility created by an increase in the use of non-dispatchable renewables and a decrease in the number of dispatchable fast-start fossil fuel plants may cause difficulties in managing networks, i.e. balancing supply and demand. Interviewees from network companies argued that such difficulties can be resolved by adopting different sources of flexibility, such as demand side flexibility. As a result, network companies are likely to enter into contracts with their customers to procure flexibility and/ or aggregators that can procure flexibility from a number of sources, rather than have "*direct control*" over their network (I1 – Academia). Here, such difficulties in managing networks may bring about opportunities for new entrants with different business model innovations to flourish, e.g. energy service providers who aggregate flexibility, consortia who manage consumer's demand (section 4.1.2.2) or a digitised technological platform for flexibility providers and users to trade flexibility in real-time (section 4.1.3). An aggregator (I27) argued these opportunities emerge from the market forces of "*crazy*" volatility which are created by the changes in generation mix. In the future, the need to maintain and improve flexibility will require changes in relationships between key actors in the sector, i.e. architectural innovation.

4.7 DOMINANT ENERGY DISCOURSE COALITIONS

The findings from above sections show that interviewees have diverse assumptions about transitions of the sector along several themes including change (section 4.2), timeframe and nature of change (section 4.3), stability (section 4.4), the role of regulation and policy in transitions (section 4.5) and the expected outcome of these transitions or goals of transition (section 4.6). This section firstly summarises interviewees' diverse assumptions, compares these assumptions with contemporary energy discourses in literatures to reveal five groups of interviewees (i.e. five discourse coalitions): (1) economic rationalism, (2) administrative rationalism, (3) ecological modernisation, (4) consumer sovereignty and (5) energy democracy. Secondly, some other discourse coalitions emerged solely from the data are identified. They are (6) technology focus and (7) energy flexibility.

4.7.1 Dominant discourse coalitions with insights from literature

In Chapter 2 (section 2.6.2), five contemporary energy discourses are identified from the literature (1) economic rationalism, (2) administrative rationalism, (3) ecological modernisation, (4) consumerism and (5) energy democracy. These discourses are dominant because they fulfil (1) Discourse structuration and (2) Discourse institutionalisation (Table 2.5). Interviewees with diverse assumptions about transitions identified in this chapter (section 4.2 to 4.6) broadly fit with main characteristic of these five contemporary energy discourses (Table 4.1) and form five dominant discourse coalitions within GB's electricity sector. This section shows how each discourse coalition is adapted from literature.

4.7.1.1 Economic rationalism

Economic rationalism is one of the discourse coalitions identified from the assumptions of interviewees in previous sections. This discourse coalition shares the following three main assumptions which match the characteristics of economic rationalism in literature.

First, a majority of interviewees assumed that both utilities and consumers in the industry act rationally following economic choices. They will be incentivised by economic benefits and act to maximise this. For example, consumers will change their demand patterns following their subscribed time-of-use tariff or the owners of battery storage will participate in wholesale market arbitrage to realise price benefits (see section 4.4.2.6 – Market design barriers). Actors in economic rationalism are "*motivated by material self-interest, and pursuing it rationally*" (Dryzek, 1997, p.113). This rational behaviour in economics means maximising economic benefits.

Second, by assuming that consumers and the industry act rationally, these interviewees advocate the roles of market and its dynamic pricing mechanisms and signals in delivering transitions (section 4.4.2.6 – Market design barriers. Actors who are grouped in this discourse coalition emphasise market mechanisms '*to knock customers into different behaviour*" (I23 – Network company). This assumption is similar to the basic entities established in economic rationalism discourses which are markets and prices. Market and its mechanism (including prices) are able to achieve public ends and social welfare (Dryzek, 1997, pp.102, 104)

Table 4.1: Discourse coalitions and their main characteristics from literature – adapted from Dryzek (1997), Hajer (1993; 1995) and Urry (2016) and main assumptions of interviewees.

Discourse coalitions	Main characteristics from literature	Main assumption of interviewees
Economic rationalism	Definition: the intelligent deployment of market mechanisms to achieve public ends. - Basic entities: markets, prices - Relationships: competition - Agents: self-interested, i.e. act rationally - Metaphors: free	- Both utilities and consumers in the industry act rationally following economic choices - Market with its dynamic pricing mechanisms and signals has an important role in delivering transitions - Regulation should apply lighter intervention into the market
Administrative rationalism	Definition: a problem-solving discourse which emphasizes the role of expert rather than the citizen or producer/consumer in social problem solving, Cost-benefit analysis and risk analysis are used to inform policy - Basic entities: administrative state (government), experts, managers - Relationships: people subordinate to state, experts and managers control state - Agents: experts and managers, motivated by public interest - Metaphors: the administrative mind	- Both utilities and consumers in the industry act rationally following economic choices - Evidence from researches (e.g. cost-benefit analysis) and market trials are important for state administration - Government and regulation should provide long term direction for the development of the industry
Ecological modernisation	Definition: a restructuring of the capitalist political economy along more environmentally sound lines - Basic entities: complex systems, capitalist economy, the state - Relationships: environmental protection and economic prosperity go together - Agents: motivated by public goods - Metaphors: reassurance	- Clean and economic development can be together in governmental policy - The government has an important role in driving transitions and should have decarbonisation at the centre of the energy policy
Consumer sovereignty	Definition: the manufacturing of products should be based on consumers' preferences - Basic entities: consumers' identities, the industry - Relationships: the industry subordinate consumers, economic activities should satisfy consumers - Agents: consumers, the industry	- Consumers' identities such as their engagement and trust should be focus. - Innovations and operation in the industry should take into account consumers' preferences.
Energy democracy	Definition: the move from fossil fuel to renewables and from the power of large energy companies to prosumers - Basic entities: decentralised energy system, democratic decision making, prosumers - Relationships: prosumers and renewables, workers and trade union - Agents: prosumers	- Consumers potentially become "prosumers" and lead the transition - These prosumers may be subjected to new ways of being governed.

Third, the discussion (see section 4.5 – Regulation and policy) revealed the assumptions of some interviewees that regulation and regulatory structure may prevent the sector from addressing various existing barriers and also constrain the development of the sector, i.e. transition. For these interviewees, a regulatory regime might not be appropriate because,

> *"…the industry and investors need to acknowledge and embrace arguably that regulation will lag rather than lead the market"* (I27 – Aggregator).

This assumption matches one of the characteristics of economic rationalism which opposes administrative regulation (Dryzek, 1997, p.14). The market should be free, rather than being "*command and control*" by government intervention.

Overall, as some interviewees' assumptions about the futures ascribes to economic rationalism discourse, they are grouped in "*economic rationalism discourse coalition*". This discourse coalition rests on a belief that market mechanisms will work in the future, based on economically rational behaviour of consumers and the industry. This discourse coalition expects lighter intervention of regulation into the market.

4.7.1.2 Administrative rationalism

In this discourse coalition, interviewees follow three main assumptions below which fit within administrative rationalism discourse in literature.

Firstly, interviewees in this discourse also shared the assumption of consumers' and industry economically rational behaviour. As identified in section 4.4.2.2.3, the majority of interviewees believes that the industry will invest in a specific type of generation technology when it is subsidised regardless of their perspectives towards subsidies (i.e. whether they are proponents of opponents of subsidies). This assumption fits within administrative rationalism in the sense that actors, including the State, act rationally, to achieve public interests (Dryzek, 1997, p.75)

Secondly, some interviewees pay attention to the importance of research in the sector. Research plays an important role in innovations (e.g. in case of EVs in section 4.2.2.1 – Current changes). However, many publications in the field are used to provide information for consumers and the industry, not for government, e.g. CMA (section 4.4.2.4) or WWF/ Vivid economics (section 4.4.2.2.2). These interviewees who consider the role of research only to inform consumers and the industry instead of the government are NOT grouped in this discourse coalition. Rather, this discourse coalition includes interviewees who consider research for state administration as in section 4.5.2 – Energy policy.

This assumption accords with the main characteristics of administrative rationalism where the government is "*informed by the best available expertise*" of experts (Dryzek, 1997, p.74). In conventional administrative rationalism, cost-benefit analysis and risk analysis are salient to inform governmental policy (not to inform consumers or the industry). Going beyond this conventional understanding of administrative rationalism, this discourse coalition proposed that market trails are also used to provide government with evidence.

Interviewees highlighted that a number of trials of new technologies or consumer-focussed innovations have already been conducted to help the industry understand about the benefits of new technologies as well as consumers. Other interviewees emphasised the importance of these market trials for the government and regulator to *“bring pressure to bear on the industry to get them act together*” (I4 – Distributed asset business). Here, these two research and market trials are intertwined to provide real evidence for state administration.

Even so, it does not mean that the role of market is emphasised. The final decision and/or power is in the hand of the government and regulation, others than market (Dryzek, 1997, p.72).

Thirdly, interviewees who argued that the government and regulation need to provide long term direction for the development of the industry (i.e. emphasise the role of government in incentivising the industry) also subscribe to this discourse coalition. As identified in section 4.5.2 – Energy policy, an interviewee criticised the government for not having any specific activities in response to good evidence and recommendation from National Infrastructure Commission (2016) for the grid strategic upgrade. This assumption is also drawn from the main characteristics of administrative rationalism where the final decision (power) is in the hand of the government and regulation (Dryzek, 1997)

Interviewees who align with the above three main assumptions are grouped into administrative rationalism discourse coalition. Overall, administrative rationalism discourse coalition rests on the assumption that consumers behaviour is economically rational and that transitions are based on evidence from cost-benefit analysis and market trials.

4.7.1.3 Ecological modernisation

The ecological modernisation discourse coalition also emphasises the important role of the government in transition. However, it rests on two other assumptions which align to ecological modernisation in literature.

Firstly, some interviewees as identified in section 4.6.1 - Decarbonisation argued that the government is able to have an energy policy which is both clean and economically driven (i.e. supports both decarbonisation and economic growth). This coalition also includes the one who shared the assumption that continuing tackling climate change does not need to be *“at the expense of economic activity”* (I28 – Government). Similarly, literature on economic rationalism also emphasises that *"environmental protection and economic prosperity go together*" (Dryzek, 1997, p.146).

Secondly, as also argued in section 4.6.1, decarbonisation should be a transition goal and as such, should be brought to the fore in energy policy. Here, ecological modernisation discourse coalition includes interviewees who emphasised the role of decarbonisation in energy policy, e.g. who highlighted that *"the thing that drives all of this [change of the sector] is its decarbonisation"* (I13 – Government). This assumption accords with ecological modernisation which is defined as a "*restructuring of the capitalist economy along more environmentally sound lines*" (Dryzek, 1997, p.141). In ecological modernisation, the goal of environmental protection such as decarbonisation is the most salient.

Overall, in this context, ecological modernisation discourse coalition emphasises the important roles of government in focusing on decarbonisation agenda, based on the assumption that a nation can both decarbonise and grow the economy.

4.7.1.4 Consumer sovereignty

Consumer sovereignty is another broad discourse coalition identified from the findings in previous sections with insights from consumer sovereignty discourse in literature. This discourse coalition comprises of interviewees with two main assumptions about consumers and the development of the sector.

Firstly, interviewees who focus on consumers' identities and characteristics in the sector are grouped in this consumer sovereignty discourse coalition. In GB's electricity sector, two main consumers' characteristics are their engagement and trust. As identified in section 4.2.2 – Electricity consumption, these interviewees do not necessarily share views about consumers and their engagement in the sector. Some argued that consumers will never engage while others believed in the active role of consumers in the future. As also identified in section 4.4.2.4 - Consumer barriers, interviewees do not share views about consumers' trust either. Some interviewees argued that consumers do not trust incumbents while others argued the reverse. Regardless of these contradictory views about consumer engagement and trust, interviewees shared the agreement that consumers always want to have control and hence, are going to play a more important central role in the future of the industry. As a result, interviewees agree that organisations need to bring consumers to the fore in their operation. This assumption is similar to consumer sovereignty discourse in literature where consumers' identity is a central concern (Urry, 2016).

Secondly, this discourse coalition includes interviewees who shared the perspectives that consumers should be at the forefront of industrial operation (section 4.2.2). In other words, innovations and operation in the industry should take into account consumers' preferences. For example, this discourse coalition is represented by the one who argued that "*we were basically going to try and bring a consumer product to market that would help individuals make a choice on climate change"* (I12 – energy supplier). This assumption also resonates with consumer sovereignty discourse in literature which emphasises the ultimate objective of the industry is to match consumers' preferences (Hutt, 1943; Menges, 2003) and consequently, satisfy consumers (Gordon and Olson, 2000).

Overall, consumer sovereignty discourse coalition takes into account consumers' identity and preferences in businesses' operation which match the main characteristics of consumer sovereignty.

4.7.1.5 Energy democracy

Beside consumer sovereignty, energy democracy is another energy discourse coalition which considers consumers and their role in the energy field. They are adapted from literature in energy democracy.

Firstly, as highlighted in section 4.2.2.1 – Current changes, consumers may potentially become "prosumers", i.e. generators and consumers of electricity in line with the development of renewables such as PVs. Hence, this discourse coalition includes interviewees who emphasise the ability of consumers becoming both generators and consumers in the future and a "*very influential segment of society which leads to innovations occurring elsewhere*" (I1 – Academia), rather than just paying attention to consumers' identity (as in consumer sovereignty). The emphasis on "prosumers" accords with literature on energy democracy where the prosumers are empowered (Morris and Jungjohann, 2016).

Secondly, as also highlighted in section 4.2.2.1, prosumers can potentially become a new political subject and are subjected to new ways of being governed. Here, this discourse coalition includes interviewees who suggested the involvement of community energy or local authorities or "*a devolution of power within energy"* (I17 – Government). Similarly, energy democracy literature also recognises the importance of democracy decision making (Tomain, 2015).

Overall, interviewees who share the above two assumptions are grouped in energy democracy discourse coalition. This coalition emphasises the potential development of prosumers who both generate and consume electricity in the future. These prosumers may be subjected to new ways of being governed.

4.7.2 Other discourse coalitions

Beside the above five discourse coalitions are two other dominant discourses which emerge from data and have been supported by almost all interviewees. They are explored in turn below.

4.7.2.1 Technology focus

Almost all interviewees expressed their views about technologies in the sector. Technologies or technological innovations are developing alongside the changes of all sub-systems (generation, consumption and distribution) of GB's electricity sector (see section 4.2). Some interviewees raised the concern over the limitations of technical aspects of innovations which may hinder the further uptake of demand side flexibility while others argued for the disruptive characteristics of technologies with examples from other sectors (see section 4.4.2.1). Some other interviewees are interested in the reduction in cost of technologies which open opportunities for technologies to be adopted. Technologies are also important in collecting necessary data for industrial operation (e.g. consumers data). By expressing views about technologies in the sector, these interviewees share their belief on the power of technologies in transitions of the sector. Technology focus forms a dominant discourse coalition in the sector (i.e. fulfil both discourse structuration and institutionalism) in the sense that most of the UK publications on future scenarios from the industry and the government concentrate on technology (Foxon, 2013).

4.7.2.2 Energy flexibility

Energy flexibility appears in the discussions and comments of almost all interviewees across varieties of topics in Chapter 4. For example, interviewees highlighted that energy flexibility is part of the current changes of the sector. Within the consumption sub-system, many trials to test the utility of new sources of energy flexibility (e.g. battery storage and demand side flexibility) are initiated and many consumer-centric innovations to incentivise consumers to provide demand side flexibility are developed (see section 4.2.2). Innovations to realise the benefits of demand side flexibility are also developed within network sub-system (see section 4.2.3). Moreover, interviewees identified many different types of barriers preventing the development of energy flexibility (see section 4.4.2). Last but not least, some interviewees described energy flexibility as a goal of transitions while others considered energy flexibility as both problems and solutions for the current system (see section 4.6.2).

Regardless of these diverse views of interviewees towards energy flexibility, interviewees shared their interest in energy flexibility. Here, energy flexibility starts to dominate the way interviewees conceptualise the transition (i.e. discourse structuration). Energy flexibility also starts to solidify into an institution (i.e. discourse institutionalism) since the government and Ofgem published "*Upgrading our energy system: smart systems and flexibility plan*" (2017; 2018).

It is noticeable that one interviewee has a plurality of assumptions and views which can fit into more than one discourse coalition. As such, that these discourse coalitions are not tidy and may have some overlaps, which will be discussed further in Chapter 6.

4.8 SUMMARY

In summary, this chapter made sense of transitions to low carbon futures of GB's electricity sector through the discussion about change and stability, timeframe, regulation and policy, and goals of transition (section 4.2 to 4.6). This discussion reveals the main assumptions of interviewees about how transitions are conceptualised. Section 4.7 adapted these interviewees' assumption and literature on dominant energy discourses (section 2.6.2) to identify five discourse coalitions (i.e. to group interviewees into five coalitions) and as a consequence, to understand how transitions to futures come about from each discourse coalition. It is noticeable that Discourses no 6 and 7 are popular among all interviewees; thus, are embedded in all futures. The other five discourses (no 1, 2, 3, 4, 5) group interviewees into five actor constituencies articulating five different futures of GB's electricity sector. These futures are not based on any pre-defined normative goal of transitions articulated for strategic planning purposes, but instead emerge from the discourse analysis focussed on the discursive utterances of interviewees in each discourse coalition. The following chapter 5 explores these five futures of the sector.

CHAPTER 5 FUTURES OF GREAT BRITAIN'S ELECTRICITY SECTOR

5.1 INTRODUCTION

Chapter 4 made sense of the transitions of GB's electricity sector by thematic analysis and the findings reveal seven different discourse coalitions: (1) Economic rationalism, (2) Administrative rationalism, (3) Ecological modernisation, (4) Consumer sovereignty, (5) Energy democracy, (6) Technology focus and (7) Energy flexibility. The main characteristics of these discourse coalitions are summarised in Table 5.1. This table also includes the interviewees grouped in each energy coalition.

It is noticeable some interviewees fit in more than one discourse coalition because firstly, their comments articulate possible different futures of the sector and secondly, they do not have a sufficiently clear vision about a single future of the sector. As such, they hold a plurality of views

Table 5.1: Discourse coalitions, main characteristics and main actors (interviewees)

Discourse coalitions	Main characteristics	Main interviewees
Economic rationalism	- Both utilities and consumers in the industry act rationally following economic choices - Market with its dynamic pricing mechanisms and signals has an important role in delivering transitions - Regulation should apply lighter intervention into the market	I3, I11, I15, I18, I20, I21, I23, I27
Administrative rationalism	- Both utilities and consumers in the industry act rationally following economic choices - Evidence from research (e.g. cost-benefit analysis) and market trials are important for state administration - Government and regulation should provide long term direction for the development of the industry	I4, I9, I19, I24
Ecological modernisation	- Clean and economic development can be together in governmental policy - The government has an important role in driving transitions and should have decarbonisation at the centre of the energy policy	I7, I8, I12, I13, I26, I28
Consumer sovereignty	- Consumers' identities such as their engagement and trust should be focus. Regardless of their engagement, they want more control. - Innovations and operation in the industry should take into account consumers' preferences.	I2, I5, I6, I10, I12, I13, I14, I22, I23
Energy democracy	- Consumers potentially become "*prosumers*" and lead the transition - These prosumers may be subjected to new ways of being governed.	I1, I9, I12, I16, I17
Technology focus	- Believe in the power of technology	Almost all interviewees
Energy flexibility	- Interest in energy flexibility	Almost all interviewees

about futures and consequently, futures are sometimes messy. This ambiguity in the boundaries of discourse coalitions and messiness of futures will be further discussed in Chapter 6.

These discourses coalitions form the basis of futures of the sector. Amongst these discourse coalitions, technology focus and energy flexibility discourses are accepted among almost all interviewees and are embedded in all futures. Therefore, they are not examined separately. The remaining five discourse coalitions with quite unique sets of assumptions about the transitions of the sector informs five different futures explored in this chapter:

(1) Economic rationalism: a 'Market-based' future.
(2) Administrative rationalism: a 'Network-focussed' future.
(3) Ecological modernisation: a 'Policy-driven' future.
(4) Consumer sovereignty: a 'Consumer-centric' future; and
(5) Energy democracy: a 'Prosumer-led' future.

This Chapter 5 introduction is followed by six sections. The first five sections describe these five futures in turn. Each future consists of four parts following an amended energy discourse analysis framework based on Dryzek (1997) (Table 2.4): (1) System components, (2) System relationships, (3) Power and (4) The metaphor of energy flexibility. The last section summaries these futures.

Each future is constructed from the interviewees' sense of system components and their relationships. Collectively, these are used to develop a systems map for each future. The systems maps are the researcher's interpretation developed with the aim to show, in diagrammatic form, what the futures look like based on a compilation of interviewees' insights on each future. It does not mean that all interviewees agree upon or have endorsed these system maps. For consistency of interpretation, in each systems map, the green line refers to GB's electricity sector in the future, the red lines show sub-systems and the blue lines feature components of the system.

5.2 FUTURE 1: MARKET-BASED FUTURE

This future vision is advanced by interviewees subscribing to an economic rationalism discourse typified by the emphasis on the economic rational behaviour of actors and the central role of the markets in achieving outcomes. Market price volatility and data are the first two system components which drive changes in other systems components. These components create market forces for actors to develop technological innovations and change their businesses.

Technological innovations and associated business model innovations is the third main system component which includes a technology platform or other home-related technologies. These technologies and consequent changes in the market are described in detail below. These technologies are supported by market mechanism. However, sometimes, the market mechanism is undermined by regulation - the fourth key system component.

These system components of this future are shown in the systems map in Figure 5.1. As this study focuses on whole system analysis, it is important to understand how the conventional system components of: generation, distribution and consumption of GB's electricity sector (Figure 2.2) change. In this future, it is noticeable these conventional system components are not evident.

5.2.1 System components

This future has four main subsystems which can be described as (1) Market price volatility, (2) Data, (3) Technological innovations and associated business models and (4) Regulation. Each sub-system has a range of elements.

5.2.1.1 Market price volatility

The volatility of the wholesale electricity market is expected to continue to increase in this future due to the reduction in traditional sources of flexibility of the system which "*hold the system together*" (I27 – Aggregator). System flexibility has and will change because of the increase of intermittent renewables' deployment from *"…two or three or four percent of the grid to 30, 40, 50 percent of the grid"* (I27 – Aggregator) and consequent reduction of dispatchable fossil fuel generation. But this has consequences for market (price) volatility:

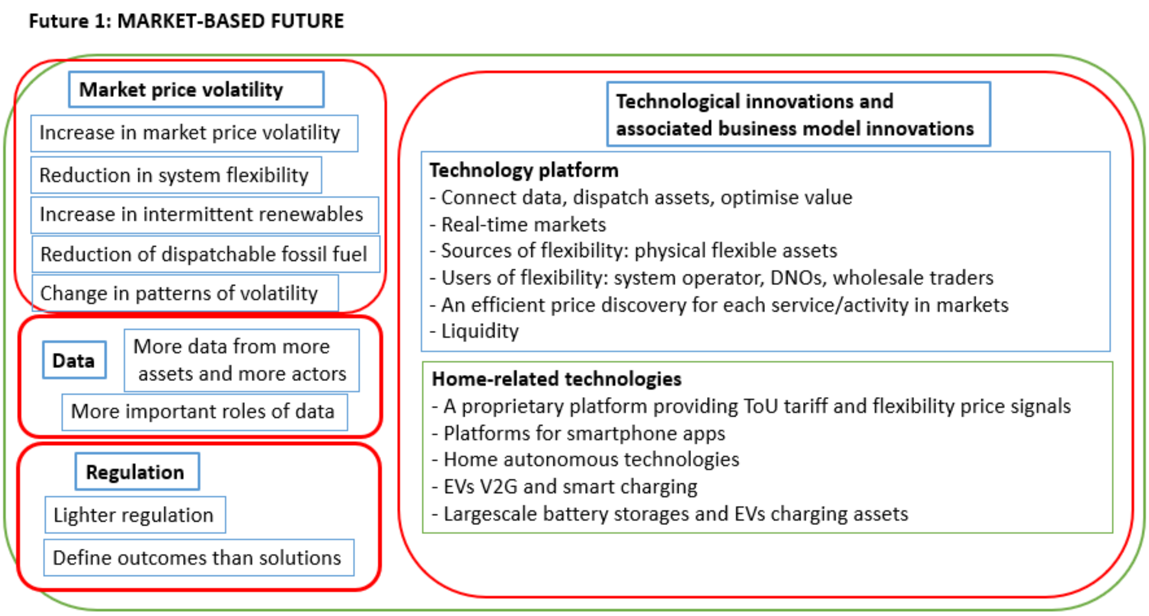


Figure 5.1: Future 1 systems map

> *"…as flexible plant is being retired, so the need for flexibility, for system flexibility, is going up, but the source of system flexibility going down. And those two effects are driving you know, never seen levels of volatility in the system"* (I27 – Aggregator).

Not only is the level of volatility anticipated to increase but *"the patterns of volatility*" (I27 – Aggregator) have also changed and is expected to change further in this future. Patterns of volatility refer to the differential day/night and winter/summer energy prices; higher in daytime and wintertime when demand is higher. However, "*all of that is now gone"* as "…*quite often power prices are now higher in the nighttime rather than the daytime"* (I27 – Aggregator). This shift is happening now and will continue in future. Two contributory factors might account for this argument: more home electricity equipment such as washing machines or EVs being operated or charged; and daytime and summer electricity capacity is fulfilled by solar power which has low or zero unit generating cost. Similarly, *"…power prices sometimes are higher in the summer than in the winter or deeply negative in the summer*" (I27 – Aggregator). Prices are higher in summer possibly because the system is served by solar power more in summer than in winter which does not cover the nighttime demand. The surplus in supply in summer may lead to the system operator paying for generation to be turned off or consumers to use more electricity, as a consequence, power prices become negative. However, there is no clear consensus of whether this market price volatility is materialised.

5.2.1.2 Data

The electricity wholesale market is not only anticipated to become more volatile but also more complex with *"lots of different things going on*" (I27 – Aggregator) such as the increase in renewable energy assets as described above, storage connected to the distribution network, more home appliances, more actors in the sector and, as a result, more data. With the increase in the amount of data, the shift is described as a change from "*a centralised stable world to a very dynamic decentralised kind of green crazy world" and "you need technology to figure it out"* (I27 – Aggregator).

Interviewees shared an agreement that there would be much more data in the future and agreed that data are going to play a much more important role in such a complex future. Data allow actors to *"be very agile to reflect the shifts in supply and demand"* (I18 – New entrant energy supplier). It means that industrial actors are able to take advantages of these data to develop technologies or change their business models. For example, energy suppliers will soon have *"data for every half an hour the day, so they'll be able to work out that you [consumers] work at night and they might give you [consumers] a better rate for buying electricity"* (I20 – Industry commentator). Here, consumers are expected to benefit from the availability of data. Energy suppliers also have benefits by optimising their business portfolio, i.e. have a better view of the amount of electricity they need to buy to match their consumers' demand.

While market volatility and complexity might increase, it arises from and also creates market forces for technologies to be developed and businesses to change and to enter the market. The following sections identify a key sub-system of this future: technological innovations and associated business model innovations.

5.2.1.3 Technological innovations and associated business model innovations

Innovations are mentioned frequently by interviewees in this future but tend to be understood as technological innovations. These innovations are currently available on the market but are expected to be further developed and become mainstream in the future. These technologies imagined by interviewees are explored below.

5.2.1.3.1 Technology platform

The innovations envisaged include a *"technology platform"* – *"a piece of infrastructure"* (I27 – Aggregator) which connects and processes data about the available sources of flexibility (i.e. physical assets which can provide flexibility) and users of flexibility including the system operator who needs to buy ancillary services, DNOs who want to manage distribution network constraints or wholesale traders who look for volatility. According to one interviewee, this technology is also able to dispatch these physical assets and optimise value at a specific real-time (at present or in future). This technology platform is a response to deal with the increasing volume of data in this future which, even now it is "*hopeless to deal with that with human beings"* (I27 – Aggregator). The platform visualisations of these data allow actors from different traditional markets (wholesale, balancing market and network constraints) to compete. This means that,

> *"It's [the technology platform is] trying to create a more dynamic real-time market for different sources of energy flexibility and different users of energy flexibility"* (I27 – Aggregator).

This technology platform opens an opportunity for two types of blending: (1) the blending of different traditional value pools and (2) the blending of different traditional business models. Firstly, this platform will potentially create an "*interchange between historically different value pools"* (I27 – Aggregator). There are some traditional markets/ value pools which generate separated value for actors including (1) National Grid system balancing ancillary market, (2) traders' wholesales volatile market and suppliers' tariff market and (3) DNOs local constraint management market. It is expected that *"markets [real-time markets mentioned above] will emerge that allow* *interoperability financially speaking between those different value pools"* (I27 – Aggregator). It means that the economic value (money) will flow between these different traditional value pools/ markets. This would totally disrupt the current market designs, even *"entirely destroying the need for certain market actors to exist at all"* (I27 – Aggregators) such as traditional energy suppliers and traders because "*a pure commodity buyer and seller is a road to destruction*" (I27 – Aggregator).

In order for this expectation of markets allowing the blending between different value pools to occur, it is argued that an efficient price discovery process (i.e. the process of determining the price) reflecting a real value of a service/ an activity in each traditional market described above needs to be established. Nevertheless, this expectation is unlikely to be met quickly:

> *"…that's going to take some time … once the price discovery process has run its course and then the interoperability between those different markets is allowed and liquid enough to genuinely rely on the amount of volume that you need to fix the constraint or balance the system …, then you can let market forces rip entirely…then the allocation of electricity flexibility between these fundamental value pools will be driven by almost like an auction process who has the most expensive problem that needs fixing"* (I27 – Aggregator).

The sense of letting '*market forces rip*' again emphasises the role of the market mechanism in this future. The "real-time" markets in this future are expected to secure liquidity in order for flexibility to be allocated to the users of flexibility who value it the most. The value of flexibility will be 'stacked' across the traditional markets where the same sources of flexibility (assets) can deliver flexibility services to different users (at different time or concurrently) as in the case of battery storage (see section 4.4.2.6) although this particular interviewee did not mention about this value stacking.

On the other hand, an interviewee from a network company raised the concern that DNOs might be unable to get the flexibility that they need by depending on markets to procure needed flexibility services, which threatens the reliability of the network and "*undermine the control that [DNOs] have"* (I15 – Network company). This happens if the value for local constraint management of DNOs is smaller than that in the wholesale market. However, an interviewee from another network company argued that this concern does not potentially prevent DNOs from procuring flexibility from markets. This interviewee expected liquid markets and highlighted when the "*liquidity increases*", there would be "*enough resources essentially on the network at other specific locations to be able to help [reduce network constraints]"* (I23 – Network company). In case the price signals that DNOs send is weaker than the price signals from the wholesale market and DNOs are unable to procure flexibility from markets, they can upgrade the network instead. Here, it is uncertain whether the "*blending of value pools*" is realistic because interviewees with a network perspective expresses contradictory opinions.

With regards to the second blending mentioned above, conventionally, asset owners and energy traders are operating separately. Asset owners usually generate revenue by building and operating assets. Using this platform, they are *"building their own trading desk and their own route to market*" (I27 – Aggregator). Such penetration of asset owners into the trading electricity operation reduces the role of traditional traders and suppliers. As a result, they are looking to build different routes to market. They and other new entrants can also come into the markets with new technologies, participating in the area of *"assets (networks) or with trading or with constraint management"* (I27 – Aggregator). Examples of how new entrants or energy suppliers seek new routes to market via technologies is described in the following section – Home-related technologies

5.2.1.3.2 Home-related technologies

In domestic homes, many other technologies are also required as part of the new future system including technologies related to smart meters (e.g. a proprietary platform), autonomous technologies or EVs to grid with associated business models. The adoption of these technologies also reflects diverse views of industrial actors in terms of consumers' behaviour.

Smart metering is already available in some consumers' homes. However, according to some interviewees, the benefits from smart meters are not fully harnessed. A potential mainstream technology in this future should be able to *"genuinely record how much electricity people are using in particular in more or less real-time"* (I18 – new entrant energy supplier). These electricity uses are expected to be translated into a time-of-use tariff by energy suppliers and provide *"flexibility price signals"* (I18 – new entrant energy supplier) for consumers to shift their demand to time of low prices. The technology is called a "*proprietary platform*" by this new entrant. With these flexibility price signals, consumers are, from energy suppliers' perspective, expected to act rationally following economic benefits.

Such rational behaviour of consumers also creates the expectation that smart phone apps for energy pricing and other consumers' services will continue to evolve and energy suppliers will become "*platforms for those [smartphone] apps*" which connect with consumers (I18 – New entrant energy supplier). In this case, consumers are assumed to not only behave rationally and engage in consuming electricity in the most cost-effective way but also trust new entrant energy suppliers rather than incumbent energy suppliers because "*there's been a lot of bad behaviour over the past 14 years of the Big 6 energy companies*" (I18 – New entrant energy supplier).

Other interviewees with aggregator perspective or from an incumbent energy supplier company were less convinced of such rational behaviours, suggesting that consumers "*probably won't spend any time at all worrying or doing anything about when or how they use energy"* (I27 – Aggregator) because *" energy is not very interesting to the average person"* (I11 – Incumbent energy supplier). Instead, "*powerful autonomous technologies*" will do the work with the support of market price signals. For example,

> *"…their car will automatically react to price signals about when it's more efficient to charge. Their washing machine will turn on and off dynamically responding to those price signals… They might get paid money for providing capacity from their heating or their car or whatever, but I don't think they'll think about it"* (I27 – Aggregator).

Assumptions of consumer rational behaviour will continue to shape the business models of other new entrants with EVs and battery storage technologies, especially EVs to grid (which assumes to include EVs smart charging). This model allows power stored in EVs batteries to be fed back to the grid when needed and vice versa to help with system balancing, as proved in California where electric vehicle batteries are used for "*managing the gradient of the duck curve when the PV falls off in the evening"* (I11 – Incumbent energy supplier). The Duck curve shows the imbalance between solar power generation and electricity demand during a 24-hour day. In this model, consumers are expected to participate and sign their cars up to a tariff because *"there's a monetary value in doing that, bring their bills down"* (I11 – Incumbent energy supplier).

However, another interviewee did not agree that Vehicles to grid and smart charging technology of EVs would be feasible or attractive in this future because,

> *"…Why would you [consumers] earn twenty pence to aid the grid that you are paying for already? ...People aren't engaged, electricity is really cheap, no one knows who their suppliers are, really"* (I21 – Investor).

Instead, according to this interviewee, a business model with large scale battery storage connecting to a transmission grid and discharging this power for a chain of electric vehicle charging assets is more feasible in the future. This model not only helps the system to store excess power from renewables but also addresses the range anxiety of EVs' users (by the increase of EV charging assets) and supports the further uptake of EVs.

However, it is unclear whether these technologies including the technology platform or any home related technologies are supported by all actor constituencies because each technology is described and supported by an individual actor and/or without any shared commentaries from other interviewees. Despite this lack of common support, these technologies are argued to work with market price signals. Nevertheless, regulation is argued for *"damping down the price signal"* (I27 – Aggregator). The following section looks at regulation.

5.2.1.4 Regulation

Interviewees ascribing to economic rationalism expect a future with less intervention from regulation into the market, compared to current market arrangements where the regulator defines rules for industry actors to operate. In this future, regulation is anticipated to *"lag rather than lead the markets"* (I27 – Aggregator). An interviewee with an investment perspective agreed and commented *"I don't think that they [the government and regulator] promote the change [of the electricity sector]. Actually, they are running quite hard to keep up with it"* (I3 – Investor). Another interviewee highlighted that that the traditional structure of the market with generation, transmission and distribution, and supply (consumption) on which the regulatory rules are based on does not exist. Therefore, it is expected that:

> *"the regulator needs to then acknowledge that a thousand different varieties of market are emerging, so rather than try to prescriptively define how each one of those new markets should work which is too complicated, you [the regulator] should agree some broad principles by which any of those new markets are emerging should operate…the regulator will shift from prescribing solutions to prescribing outcomes"* (I27 – Aggregator).

This expectation again emphasises the role of the market in the transition of the sector to future. The market is able to lead the transition while regulation should facilitate by proposing outcomes (e.g. smart and flexibility system) without direct intervention. For example, market actors who operate renewable assets (e.g. wind farms, solar farms) should not get paid as a compensation for their curtailment because such compensation *"is destroying some price signals that would otherwise encourage innovations"* (I27 – Aggregator).

5.2.2 System relationships

The above system and its components will require and bring forth new sets of relationships. Interviewees highlighted that the traditional, distinct boundary of generation, transmission and distribution and supply (consumption) will disappear,

> *"the underlying market reality does not reflect the world of generation, transmission distribution supply… a thousand of flowers are blooming, not four"* (I27 – Aggregator)

Here, no energy company will be only operating in a market defined by single generation, distribution and consumption. Rather, with technologies, energy companies will open new propositions or change the way they offer products to enter new markets in different sub-systems to seek profits. Similarly, new entrants will also look for more opportunities beyond the conventional business model of buying and selling electricity. This traditional boundary is blurred by the existence of the technology platform where sources of flexibility providers and users of flexibility can be connected such as the one described in section 5.2.1.3.1. As such, the relationships between actors in the industry will be tighter, but perhaps more competition between different businesses.

Interviewees noted an establishment of new relationships between new entrants and energy consumers. This new relationship will be enhanced because consumers will consider energy incumbents as non-trustworthy. Consumers are expected to realise that *“there's been a lot of bad behaviour over the past 14 years of the Big 6 energy companies”* (I18 – New entrant energy supplier). Some interviewees argued that this new relationship can be based on active consumer engagement who participate in nearer time-of-use tariff or EVs vehicle to grid model with a financial incentive. In contrast, others highlighted that this new relationship can only be on the basis of passive consumers engagement through autonomous appliances. However, this new relationship does not go outside the boundary of the consumption sub-system.

The traditional relationship between the regulator and the industry is also likely to change as the regulator is expected to define outcomes rather than setting rules to manage the system (see section 5.2.1.4). This change in relationship is in line with economic rationalism which prefers market without much intervention.

5.2.3 Power

Power between actors might also be transferred, as assumed by interviewees. As the regulator is expected to apply lighter regulation to the market, market actors will have a chance to exercise power over the regulator. Among these market actors, competition is exercised and it is expected to lead to the future where new entrants with new technologies have power over incumbents. Moreover, the most powerful businesses in this future are the one which both “*make money in today's market*” and “*plan to survive for 10, 20, 30, years in the future”* (I27 – Aggregator). Such planning and designing of businesses for an uncertain future will help businesses to be successful.

However, the power of actors is not as emphasised as the power of market and technologies in this future. Market mechanism is argued to force changes in human actors including organisations with new technologies and benefit seeking interests and as a consequence, engender transitions. Technologies are anticipated to emerge in response to market mechanism.

In this future, the possible changes in power relationships between consumers and technologies are evident. New entrants suggest that consumers will actively use their smart phone apps to check energy prices and as such, energy suppliers will offer a nearer to real-time time of use tariff to consumers and can also potentially become "*platforms for smartphone apps"* (I18 – New entrant energy supplier). Moreover, consumers do not trust electricity incumbents and could deliberately choose new entrants to the market. In contrast, in this future, some interviewees believe autonomous technologies could replace human power and encourage consumer passivity.

5.2.4 The metaphor of energy flexibility

Energy flexibility is a key metaphor in this future. *Energy flexibility* is explicitly described as a necessary component creating value for different traditional markets such as (1) the balancing market, (2) the wholesale market and (3) the network constraints management by an aggregator. Here, the interviewee considered energy flexibility as valuable and also proposed some new markets where the value of energy flexibility can be captured, e.g. real-time markets where these traditional markets/ value pools of flexibility are blended. As a result, value of energy flexibility might be able to be stacked in this future. Energy flexibility is able to constitute architectural innovation which involves changes in the relationships between traditional markets, i.e. the traditional market structure. With energy flexibility, the traditional market structure is totally replaced by a mass variety of markets, new entrants and technologies.

On the other hand, a new entrant energy supplier referred energy flexibility to the time-of-use tariff model where consumers are incentivised by "*flexibility price signals*" to participate in demand side flexibility. Energy flexibility in this instance is considered as a market mechanism. By implying that the market has its mechanism, this interviewee considered the electricity system as a "*machine*" which performance and operations can be changed or fixed by adding or removing some components. As such, the electricity system in the future will work efficiently by adding energy flexibility component without the needs to change the traditional market structure.

In this future, energy flexibility is framed differently from two different views of an aggregator and a new entrant energy supplier, architectural innovation which involves changes in system architecture and a technological system component which can be added, respectively. However, regardless of these different conceptualisations, energy flexibility is expected to bring about values to the future system.

5.3 FUTURE 2: NETWORK-FOCUSSED FUTURE

Future 2 is based on an administrative rationalism discourse in which research and market trials are deemed vital in providing evidence for state administration. In this future, energy flexibility is explicitly supported by interviewees ascribing to administrative rationalism, i.e. administrative rationalism discourse coalition. Hence, the first key system component of this future is evidence-based energy flexibility including research and market demonstration. These two forms of evidence are key in this future and used to support the changes in network. Hence, this future is named network-focus. Here, energy flexibility is *"all about understanding network capacity and energy throughput rather than maximum demand"* (I24 – Network company). This understanding is expected to come from evidence. Energy flexibility includes and is reliant on both "*demand side flexibility"* and *"grid automation*". These are two key system components of this future. The final key system component in this future is regulation which is argued to support demand side flexibility than grid automation.

The key components of this future are shown in Figure 5.2. Similar to Future 1 – Market-based future, the conventional components of the system (generation, distribution and consumption) do not feature in this future.

5.3.1 System components

From the discussion of interviewees, this section describes four main sub-systems identified in this future (1) Evidence-based energy flexibility, (2) Demand side flexibility, (3) Grid automation, and (4)

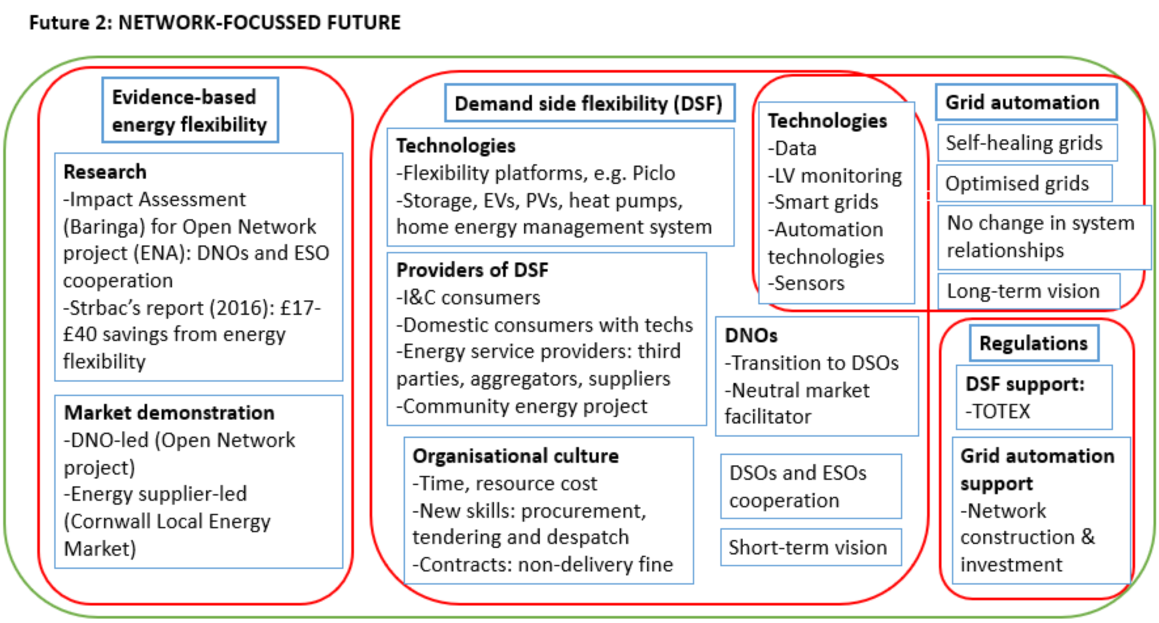


Figure 5.2: Future 2 systems map

Regulation towards demand side flexibility and grid automation. There are some overlaps between demand side flexibility and grid automation in terms of technologies as discussed below.

5.3.1.1 Evidence-based energy flexibility

The first sub-system is comprised of activities being conducted to prove the value of energy flexibility in this future. Interviewees consider two main forms of evidence used in regulation and policies including (1) research and (2) market demonstration. Research projects are "*kind of feasibilities of studies and learnings to be taken"* and market demonstration projects are where these learnings are put "*in place to see how they work in real life"* (I9 – Network company).

An interviewee noted the important role of an Impact Assessment done by Baringa consultancy firm in Open Networks project which sets out five Worlds for enabling demand side flexibility (Askew and Sinclair, 2019). Basing mainly on quantitative cost-benefit analysis of Five Future Worlds identified in the Open Network project, this impact assessment concluded that World B where DNO and National Grid as a system operator cooperate to procure flexibility is "*an overall optimal system solution*" (I19 – Network Company).

Also emphasising an important role of economic cost-benefit analysis, another interviewee mentioned about a report published by Strbac et al (2016a, p.16) which uses economic analysis to anticipate that "*the deployment of flexibility technologies could save the UK energy system £17-40 billion cumulative to 2050*". This value of flexibility (i.e. net benefit) flows towards consumers because *"if it is true, customers can save between £17bn and £40bn a year"* (I4 – Distributed business asset). Here, energy flexibility is attached a value and futures are achieved through economic cost-benefit analysis. Transitions, hence, can come about through governmental energy policies and regulation after carefully consulting scientists who proved their advices by cost-benefit/ modelling analysis.

However, interviewees argued that market trial would be more important in this case because nobody knows "*which of the £17bn to £40bn is the right number?"* (I4 – Distributed business asset). Market trials or demonstration is needed *"to really try to test the kind of the assumption around how flexibility will work in future"* (I4 – Distributed business asset).

Such market trials could be considered as the second, demonstration phase of research modelling cost-benefits in *"real-life"* (I9 – Network company). While market trials are expected to be conducted by industrial actors, including both energy suppliers and network companies, there are divergent views on who should lead. For example, an interviewee argued that network companies should *not* take the lead, for example in the Open Network project run by the Energy Network Association (ENA).

> *"Our view is ENA is the trade association for the DNOs…We don't let the people who have the vested interest in this run the trial programme… we need to go faster"* (I4 – Distributed business asset)

In contrast, another interviewee expressed preference for the flexibility market in the demonstration project to be operated by DNOs but considered energy supplier-led market trials such as the Cornwall Local Energy Market, run by Centrica (an energy supplier) can "*gets the same result ultimately*" (I19 – Network company). It means that regardless of these different views on leadership, market trials on energy flexibility are expected to prove the value of flexibility where network companies are either able to procure the service or to contract with whoever can reduce or increase the demand at specific times (I19 – Network company). Interviewees also hope that from market trials, *"a combination of solutions will come to market"* (I9 – Network company). By emphasising the role of market demonstration, this future extends the boundaries of administrative rationalism and moves closer to economic rationalism.

According to the interviewees, from analyses and market trials, three areas of energy flexibility are identified: alternative connections, demand side *flexibility* and grid automation (I24 – Network company). "*Alternative connections*" means "*putting in a connection agreement with a customer on demand or generation side that [DNOs are] allowed to control [their demand or assets]…in return for a lower use of system charge or a cheaper connection cost"* (I24 – Network company). While "*alternative connections*" are said to be widely used by DNOs at present, the demand side flexibility and grid automation are at trial phase and expected to become mainstream in the future. The following sections look at demand side flexibility and grid automation.

5.3.1.2 Demand side flexibility

The demand side flexibility sub-system arises as one of the solutions which DNOs could employ to resolve distribution network constraints instead of upgrading the distribution network. These solutions refer to market innovations where market actors, who have available flexibility, contract with DNOs to offer this flexibility to DNOs. As an interviewee explained,

> *"Rather than upgrading a substation or building a new distribution feeder in a certain area, we might be able to go to the market and say 'Look, we need additional capacity in this area'… and take what flexible solutions are out there to help us sort of minimise that cost ultimately"* (I19 – network company).

By focusing on solutions available from the market, the development of demand side flexibility again goes beyond the traditional characteristics of administrative rationalism. In order for demand side flexibility to work in this future, several elements need to be in place, including (1) Technologies, (2) Business model innovations (3) Contract terms (4) DNOs skills and (5) Regulation.

5.3.1.2.1 Technologies

Data and information are argued to play the most important role in demand side flexibility. Hence, most of the technologies mentioned below are for network companies to gather and distribute data. As an interviewee highlighted,

> *"what I [a network company] need to have is the data available to be able to share it with any of those types of organisations or an individual customer if they wanted to do it themselves*" (I24 – Network company).

Low voltage monitoring (LV monitoring) and smart grids are network technologies which will be key to this future for DNOs to understand *"how much energy is going through the system and it's about moving bits of energy from a peak to a trough"*, rather than simply understanding the maximum electricity demand (I24 - Network company). LV monitoring will be essential in developing smart grids which allow two-way flows of information about electricity consumption (Langendahl *et al.*, 2016) . The two-way flows of information enable the network companies to "*understand what the network's really doing"* (I24 – Network company) or visualise which part of the network needs intervention. As an interviewee highlighted,

> *"If you can imagine the world where you have a smart gird here and monitoring down here, then flexibility will work"* (I4 – Distributed asset business).

Network companies are also active in developing technological flexibility platforms. One example mentioned by an interviewee from a network company is Piclo flex platform which an interviewee thought "*all [DNOs] are using*" and "*was started by WPD [Western power distribution network]"* (I19 – Network company). This platform can "*highlight where the issues are on the network and then allow the platform to basically offer solutions to help remove that congestion or whatever it happens to be"* (I19 – Network company). Via this platform, DNOs are able to see the available solutions, e.g. which market actors have energy flexibility that DNOs are able to have contracts with. This kind of platform is expected to be further developed and more widespread in the future.

Home-related technologies are also expected to take part in the changes to demand side flexibility. A smart meter is one key home-related technologies in the future but there are inconsistent views over their roles. The majority of interviewees argued that smart meters can *"give [network companies] better visibility of the networks"* (I19 – Network company). In contrast, others argued that smart meters need to be placed in the connection with LV monitoring and smart grids at network level to provide network companies in general and DNOs in particular with such visibility.

Other technologies include storage technologies, PVs on household roof tops, EVs, heat pumps, home energy management systems. These technologies are argued to help consumers to have *“more control over when and how they use electricity”* (I19 – Network company). In this future, the role of network companies is to:

> *“understand how that's going to work, and … design a system that essentially supports consumers doing what they want with their technologies”* (I19 – Network company)

Networks companies not only need to change in response to changes in technologies in domestic homes but also to understand how they can take advantages of the changes in relationship between technologies and consumers to bring value to consumers. In this instance, consumers are the actors who control their technologies at home.

However, another interviewee expressed the perspective that energy service providers are going to exert control over these technologies and provide demand side flexibility to network companies *“as part of either a community energy project or as part of an aggregated portfolio or through the supplier”* (I9 – Network company).

The following section provides further discussion on consumers and providers of demand side flexibility.

5.3.1.2.2 Providers of demand side flexibility

Interviewees highlighted that *“one of the big changes is the types of providers that are providing us with flexibility”* (I9 – Network company), changing from traditional large to less “*traditional technology types and smaller providers”* (I9 – Network company). They include industrial and commercial consumers (I&C consumers), distributed generators, aggregators, suppliers, battery storage and domestic consumers. Some issues with these providers are raised.

In terms of end consumers including both I&C consumers and domestic consumers, although value of flexibility is argued to flow to them (I9 – Network company), there are diverse views over whether they want to get involve in energy flexibility. Regarding I&C consumers, an interviewee from a distributed asset business expected I&C consumers will be active in getting involve in energy flexibility, following economic incentives. For example,

> *“A massive car manufacture can save themselves £100 thousand pound by doing some stuff on the market [for a day], they gonna do it, aren’t they?”* (I4 - Distributed energy business)

However, an interviewee from a network company, also share the same perspective that I&C will act rationally for which they will be rewarded, did not anticipate that they will get involved directly into energy flexibility. It was argued that although the benefits they gain from providing demand side flexibility are significant, it is *"a small additional revenue stream"* (I9 – Network company) which does not make them become an active provider.

Similarly, domestic consumers will rely on market integrated technologies to do this for them and will not actively control or provide energy flexibility. For example*, "our view is that the consumers won't go on the platform and say you can shift my fridge or turn if off in this half hour to get [a very small amount of money]"* (I4 – Distributed energy business). Also, from a network perspective, network companies do not expect to work directly with domestic consumers to procure their flexibility, because,

> *"…one household and one EVs, etc wouldn't provide a level of flexibility that we're looking for and I think it would still require somebody to aggregate or to pool together a whole street or whole town"* (I9 – Network company)

Interviewees agreed that third parties, aggregators and suppliers are expected to become intermediates between consumers and DNOs. They are called *"energy service providers – a new breed of organisations who will manage those things [technologies] on your [consumers] behalf"* (I24 – Network companies). Energy service providers on one hand will help consumers to manage their energy consumption, on the other hands offer demand side flexibility to network companies.

There are diverse opinions around the roles of energy suppliers. An interviewee argued that supplier is able to become an energy service provider because it *"has already have a relationship with the consumers"* (I9 – Network companies). In contrast, another interviewee speaking of traditional energy suppliers noted that *"they've got a terrible reputation"* (I24 – Network company). As such, energy service providers might replace traditional roles of energy suppliers,

> *"Whether you still have an energy supplier for the kilowatt hours consumed or whether ultimately that [service] becomes a kind of wholesale product that is billed to these energy service providers, I don't know and that really depends on how well the energy supply, energy retail businesses perform"* (I24 – Network company).

This comment suggested a new way of electricity supply and billing. However, it is uncertain whether this new way will be feasible in the future because it means that the regulator needs to amend its current design to allow multiple non-traditional energy suppliers, who may not be able to fulfil some essential tasks of traditional suppliers (e.g. deliver government schemes), as noted by an energy supplier (see section 4.4.2.6).

Community energy projects are also highlighted to be another type of energy flexibility provider which aggregates the energy flexibility from domestic household. Seen in this way, community energy project deviates from its traditional role of connecting local generation (e.g. solar farm of CHP).

The following section looks at the changing business models of DNOs to DSOs.

5.3.1.2.3 Distribution system operator (DSO)

There is a consensus among interviewees that DNOs will transition to Distribution system operators (DSOs), especially when technologies such as LV monitoring, smart grids and smart meters are in place. An interviewee suggested that *"we [the sector] will be in the position where the DSOs model is proved to work"* (I4 – Distributed asset operator). A common view is that becoming a DSO, a DNO

> *"needs to essentially transform their business so that they will be operating their network at a local level, and what I mean by that is they need to become a lot more commercial essentially, they're going to be enabling new flexibility markets, and procuring services from those"* (I9 – Network company).

However, an interviewee argued that buying energy flexibility from the market is *"not the future, it is part of it, but not the whole thing"* (I24 – Network company). This perspective undervalues demand side flexibility and will be explored further in section 5.3.1.3.

Becoming a DSO may involve being a neutral market facilitator. In order to "*neutrally facilitate a market"* (I24 – Network company), DNOs will need to *separate* the tasks of operating the distribution system (being a DSO) and the tasks of owning and maintaining the distribution network (being a DNO). However, another interviewee believed that *"You would only split it [the functions of DNO and DSO] if you can identify that it makes sense to split"* (I19 – Network company).

DNOs becoming DSOs will be a disruptive change to the system operator. An increase in providers of demand side flexibility (see section 5.3.1.2.2) coming into flexibility markets (i.e. National Grid's balancing market in this case) brings about competition, a liquid market and as a result, reduce market prices and consumer's bills. However, when DNOs become DSOs and trial more markets for flexibility,

> *"…if more markets become available, I think you may start to see a dispersal of those providers, that're perhaps offering into ourselves, may start to offer into other providers and other markets which then potentially could make the market less liquid and see those prices come up again".*

5.3.1.2.4 Organisational culture

This section explores the organisational culture of network companies in response to the expected demand side flexibility.

An interviewee highlighted that *"engaging with team and trying to getting them on board to trial new approaches"* is not easy (I9 – Network company). In their culture, the difficulties that they experienced are *"the time and resource cost, priorities to implement something new"* (I9 – Network company). In other words, applying something new into the business creates more workload for their employees and their employees may not be happy about it. However, another interviewee said that they do not experience this in their culture, for example,

> *"It is funny with the other DNOs and they are having to talk about cultural change programs and winning hearts and minds, but here that's just alien. I just change policy and tell them to do it differently and they do it differently"* (I24 – Network company)

In terms of the new skills needed, some interviewees argued that new skills should not raise any issues for the development of demand side flexibility because through trials, any new skill can be learnt and is considered only *"a slight change in a process"* (I9 – Network company). However, another interviewee anticipated that network companies will need a business transformation of understanding both technical and commercial side of the network for effective and reliable demand side flexibility. Here, beside their traditional technological skills, they are expected to be also good at *"procurement and tendering procurement and despatch exercises*" (I19 – Network company). It means that they will need to think about how they procure demand side flexibility, *"whether that's over procuring to ensure delivery or whether it's putting quite stringent contracts in place"* (I19 – Network company).

In particular, designing the contract is important in demand side flexibility because the security of supply will depend on *"how good these contracts are and how well people respond to those contracts as well"* (I19 – Network company). A "*non-delivery fine*" in the contract might be needed to ensure flexibility solutions are securely offered by contract holders (I19 – Network company) but it is unclear who will enforce the fine. Moreover, an "*exclusivity contract*" which prevents contract parties from participating in multiple markets should be avoided. Here, a provider should be allowed to *"trade in the wholesale market, provide services to National Grid and provide services to local networks"* (I19 – Network company).

5.3.1.3 Grid automation

Beside demand side flexibility, grid automation is another energy flexibility option for DNOs. Hence, grid automation is the third sub-system in this future.

Grid automation refers to the flexibility of the network available from the development of technology or more specifically automation technology. It involves technologies needed for demand side flexibility such as smart meters, LV monitoring and smart grids (described in section 5.3.1.3). With grid automation, any network constraints are expected to be fixed automatically using technologies. As an interviewee from a network company noted of an outcome from a grid automation trial,

> *"I could do it using one of my smart grid solutions because I've got all this automation, a grid automation that I've got self-healing grids. If the power goes off, it will trace through and automatically find alternatives to restore without any human intervention"* (I24 – Network company).

Grid automation flexibility is quite convenient to conduct because it does not involve any change in relationships. It is anticipated to be a better solution for energy flexibility than demand side flexibility because, *"everyone stays on, everyone does what they were going to do before"* (I24 – Network company). Demand side flexibility is only deemed as a short-term solution while DNOs need times to be digitised or to put sensors/ LV monitoring equipment into the network which is "*five and a half times*" the circumference of the globe (I24 – Network company). It is expected that by 2050, DNOs will do *"sufficient digitisation on the grid"* (I24 – Network company) and as a consequence, an optimised grid will be available. Being optimised means that,

> *"…you want it [the grid] to be greenest it can be and which case I will prioritise all the renewables on and control all the demand side to make sure that renewables are fully utilized and every kilowatt hour going through is as green as possible… If you want it to be …charged as fast as possible, … I can configure it for that, I can build for that. So you tell me what mode you want me to operate the grid in and I'll program it in and it will do it. That's where this is going"* (I24 – Network company).

This vision is argued to be the future of energy flexibility over long-term, rather than demand side flexibility which is only used in short-term. However, developing grid automation seems to not have support from the government and the regulator. The following section discussed regulation in terms of demand side flexibility and grid automation.

5.3.1.4 Regulation

The regulatory framework plays an important role in incentivising DNOs to develop demand side flexibility. Currently, distribution and transmission are heavily regulated. An interviewee noted that the sector in general and DNOs in particular need to *"work through a regulatory framework and drive the change [of energy flexibility]"* (I4 – Distributed asset business). In the future, regulation is expected to not experience large changes because the current incentive mechanism – TOTEX - already works well according to interviewees. TOTEX is "*the total expenditure*" which incentivises the network companies to innovate and look for the most cost-effective way to deliver good connections for consumers by using either their operating expenditure of capital expenditure (I4 – Distributed asset business). As such, the most cost-effective way is argued to be demand side flexibility. An interviewee representing network companies noted the current network regulation to set out network revenue - the RIIO model (Revenue = Incentives + Innovation + Outputs):

> *"The RIIO regime which has a TOTEX type of model works quite well at the moment. It needs some tweaks but we think we should keep that as our investors [investors in network companies] are quite happy with that sort of model* (I19 – Network company).

However, although the current regulatory framework is argued to be quite good to incentivise network companies to develop demand side flexibility, an interviewee highlighted some issues within current regulatory frameworks that need to change in the future for grid automation to work. For example, the regulator is currently focusing on minimising electricity bill charges for consumers by reducing the level of revenues DNOs can receive currently from a consumer's bill which is "*27p per day"* (I24 – Network company). Network companies are concerned that if the regulator keeps the revenue too low, the network *"literally won't get the investment"* (I24 – Network company).

Rather, it is hoped that the regulators will take recommendations and evidence from National Infrastructure Commission (2016) and incentivise investment into network construction involving grid automation. This hope and expectation is based on the potential further uptake of EVs which may use up *"all the capacity we'd [Great Britain] built for 40-50 years probably within 10"* (I24 - Network company).

5.3.2 System relationships

The industry will be more reliant on cost-benefit analysis research in order to understand the most appropriate option for the future. Such research is likely to be done by experts from academia (e.g. Strbac), governmental organisations (e.g. National Infrastructure Commission), independent consultancy (e.g. Baringa). In this future, experts and these research institutions will have tighter relationship with the industry.

Beside cost-benefit analysis, the industry will also rely on market trials. In this case, most analysis and trials focussed on energy flexibility on the network. As such, the boundary of the system is drawn around network companies, which include DNOs and National Grid with its role as a system operator (ESO), rather than the conventional system boundary around generation, distribution and consumption. Interviewees formulating this future do not see outside this new drawn system boundary. In this new drawn system boundary, the relationship between DNOs and the system operator will be tighter as is already evident in the Cornwall Local Energy Market and other market trials, according to interviewees,

> *"The Cornwall LEM is a project… essentially, it's looking at how does co-procurement of flexibility happen between a system operator and the DNO or the DSO.*
>
> *…There are other initiatives going on that are looking at that kind of coordinated DNO to DNO and ESO to DNO interaction. And I'm sure in time, a solution or a combination of solutions will come to market that allows that whole system to all be parts of an essential one"* (I9 – Network company).

Demand side flexibility and grid automation are two options for energy flexibility for network companies in the future. They are tied together by the development of technologies including smart meters, LV monitoring and smart grids.

Demand side flexibility, it is argued, can bring about value to the network and ultimately *"help reduce consumer bills"* (I19 – Network company). This argument is supported by all interviewees ascribing to administrative rationalism. The further uptake of demand side flexibility within network companies in the future will not only bring about new sets of relationships but also alter existing relationships (also see section 5.3.1.2.2). Firstly, relationships between new types of energy service providers such as aggregators, energy suppliers and community project with network companies are set up, as highlighted by interviewees. These energy service providers will become directly providing energy flexibility for network companies. Secondly, these energy service providers will have a close relationship with consumers and help consumers to manage their technologies (e.g. their cars, their electric appliances) together with their energy flexibility. This close relationship of consumers and energy service providers may threaten the traditional relationship between consumers and energy suppliers. Traditionally, energy suppliers who are considered as the only one having direct relationship with consumers connect with consumers via supply energy and billing. In this future, consumers may get energy bills directly from these (multiple) energy service providers.

These energy service providers are expected to be the bridge for network companies and domestic consumers' relationship. Here, all interviewees in this future argued that network companies will have no direct relationship with domestic consumers. In terms of commercial and industrial consumers, whether they have direct relationship with network companies in the future depends on the economic incentives they will receive.

Among all interviewees who argued for the importance of demand side flexibility in the future, one interviewee highlighted that demand side flexibility is only a short-term vision while grid automation is a long-term future to energy flexibility to DNOs. If grid automation becomes mainstream in this future, the relationships in the sector are unlikely to change. As noted above, grid automation and other technologies will be connected to the system and automatically help the network to resolve any network constraints without the need to change any interaction with consumers. As such, there will be limited opportunity for actors coming into the sector to link consumers and DNOs.

Regardless of which option (demand side flexibility or grid automation) emerges in the future, the existing relationship between network companies and the regulator is unlikely to change. Network companies will continue to be monopolies and heavily regulated by the regulator.

5.3.3 Power

The key actors who have power in this future are the government, regulator, industrial actors (DNOs and energy suppliers) and experts. Experts conduct research on the value of energy flexibility. Market trials are then carried out by industrial actors, either by DNOs or by energy suppliers as argued by interviewees. Research together with market trials are then deemed as evidence to *"make the government and the regulator bring pressure to bear on the industry to get their act together"* (I4 – Distributed asset business). In other words, the government and regulator will use the evidence provided by industrial actors and experts to steer the industry towards this network-focussed future.

The system boundary in this future is drawn around network companies which comprises of the system operator and DNOs (see section 5.3.2). The system operator and DNOs have power in this future in the sense that they are able to re-draw the boundary of traditional electricity system. Both of them are expected to *"operate it [the network] in a more efficient and effective manner which will ultimately help reduce customer bills"* (I19 – Network company). Besides, it seems that the ultimate power of the operating system of the ESO will be shared by DNOs in this future. DNOs have more power when *"trying to manage their networks more actively"* and *"beginning to trial markets for flexibility within their own networks"* (I9 – Network company).

Energy service providers which are mainly represented by aggregators and energy suppliers also have power in this future, especially in terms of demand side flexibility. They are considered as having a power of managing consumer's home technologies and *providing* energy flexibility for network companies. In contrast, domestic consumers do not have much power in this future. Consumers are mostly passive and power is given to energy service providers who actively not only help network companies to balance the transmission and distribution network but also enable economic benefits to consumers.

Although domestic consumers may not directly have power in providing energy flexibility for network companies, they have power in driving the changes of network companies. Such power emerges together with the development of home related technologies (see section 5.3.1.2.1). Consumers are argued to have control over these technologies which make network companies change to help consumers gain more value out of these technologies. An interviewee from a DNO highlighted that "*what we want to do is to keep customers happy"*. As a result, DNOs need to keep changing when consumers change the way that they use home-related technologies,

> *"When you've got an electric car…, your expectations on both the electricity system and the service you get from others are going to be very different. You're going to be so much more annoyed if you can't get to work with your car flat. And therefore, really, the challenge for us, is how do we keep really high customer satisfaction"* (DNO)

Interviewees did not mention the power of investors to any great degree. However, investors play an important role in ensuring the operation of DNOs and are sensitive to the power of the regulator (See section 5.3.1.4). Here, regulation is anticipated by some interviewees to actively resist the development of a grid automation future if it is oriented towards reducing consumers' bills by reducing DNOs' revenue, without a focus on strategic network upgrade. Conversely, other interviewees highlighted the power of the regulator who supports transitions while incentivises networks to innovate (I19 – Network company).

The power of technologies is also salient in this future, including smart grid,

> *"If you can image the world where you have a smart gird here and monitoring down here, then flexibility will work. If you haven't, it will never work"* (I4 – Distributed asset business).

Here, smart grids are considered as a pre-requisite technology which give rise to other changes in energy flexibility.

5.3.4 The metaphor of energy flexibility

Energy flexibility is a key metaphor of this future. Energy flexibility explicitly refers to technical issues of the network, i.e. transmission network balancing or local grid constraints management. Seen in this way, energy flexibility excludes some traditional key actors in a traditional electricity system who have historically provided energy flexibility such as generators. The metaphor of energy flexibility is framed around a *whole system* of network companies and providers of energy flexibility. Here, interviewees do not realise that the changes in energy flexibility involve changes in not only distribution, but also generation and consumption.

Although there is a consensus among interviewees about such a whole system, two types of energy flexibility emerge in this future. Demand side flexibility is framed by the majority of interviewees ascribing to administrative rationalism as a market solution for network issues. Seen in this way, they see demand side flexibility can be achieved by some *adds on* such as the roll out of many technologies (see section 5.3.1.2.1), the market entrance of new actors such as energy service providers (see section 5.3.1.2.2), the change to DSO model of DNOs (see section 5.3.1.2.3) and the changes in skills and contract types (see section 5.3.1.2.4). However, demand side flexibility comprises not only changes in system components but also system relationships (see section 5.3.2). As such, it can be part of architectural innovation. The problem is that the majority of interviewees are not aware of these changes in many sets of system relationships.

The second type of energy flexibility - grid automation is supported by an interviewee from a DNO. Grid automation does not involve any significant change in system relationships. Rather, it can be achieved by a range of (automation) technologies such as smart grids, LV monitoring and sensors. By supporting grid automation, this interviewee assumes that the future can be easily achieved by adding technologies.

5.4 FUTURE 3: POLICY-DRIVEN FUTURE

This future is articulated by interviewees ascribing to ecological modernisation. Interviewees in this future emphasised the important role of government and its decarbonised energy policy in driving transitions to the future of the sector. Government comprises the first sub-system of this future. With the lead of governmental energy policy, this future comprises of many innovations, technologies and actors spanning three other sub-systems of: generation, distribution and consumption. It can be clearly recognised that conventional system components and relationship of generation, distribution and consumption are kept almost the same in this future. Figure 5.3 is a systems map of this policy-driven future.

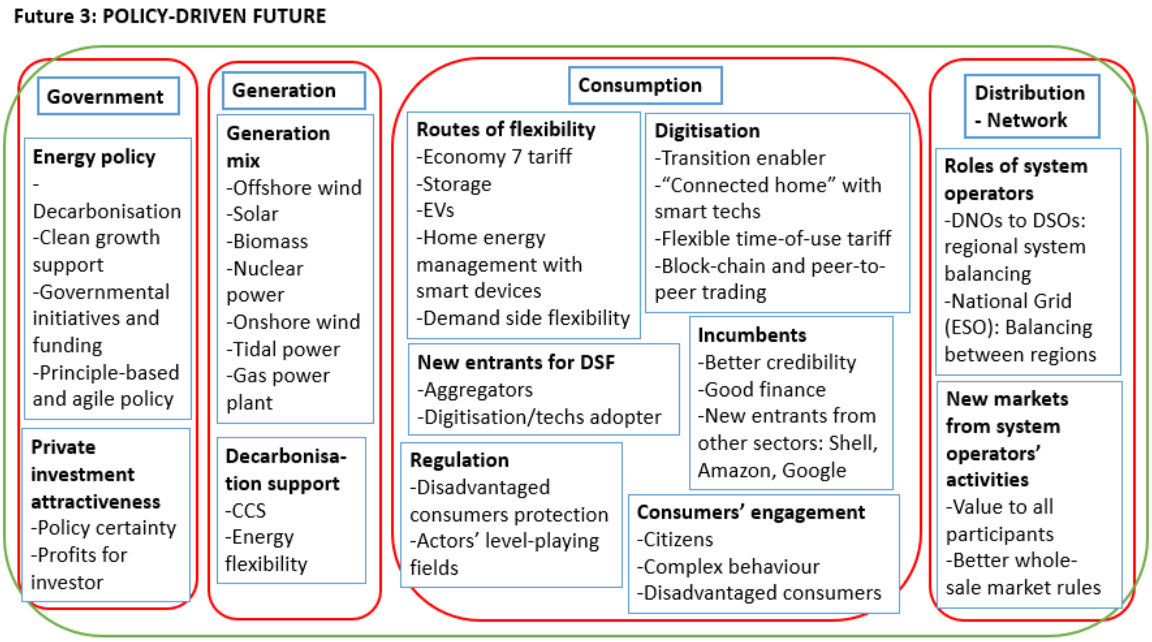


Figure 5.3: Future 3 systems map

5.4.1 System components

Based on a collective of interviewees' commentaries and discussion, this future has four main sub-systems: government, generation, distribution and consumption. The latter three sub-systems are how the industry and consumers respond to governmental policies.

5.4.1.1 Government

Interviewees shared the view that decarbonisation and economic growth should go together. An interviewee highlighted that by focusing on developing green industries, "*tens of thousands of jobs have been created*" (I28 – Government). However, some interviewees argued that the government pays attention on other issues (e.g. reducing consumers' bills) at the expense of decarbonisation (see section 4.6.1). Here, interviewees expect that decarbonisation is embedded in energy policy. Therefore, the government is expected to be at the forefront of interventions and policy innovations. In other words, governmental initiatives and funding are seen as a key to innovation infrastructure which will support the market transition. As one interviewee highlighted,

> *"Things like hydrogen, things like energy efficiency, things like the delivery of EV charging infrastructure at the sort of pace that's required. They are probably not going to happen just because the market is already doing it. They're going to need some sort of intervention"* (I28 – Government).

Although the government will have an important role in decarbonisation and supporting green industries, some interviewees highlighted that *"a clear energy policy from government"* is not yet evident (I26 – Market operator). This interviewee suggested that energy policy and regulation should focus on the *end state* of transition or be principle-based, rather than pay significant attention to the detailed processes of energy transition, i.e. a focus on *"more about the what and less about the how"* (I26 – Market operator). Another interviewee suggested that energy policy and regulation need to be more agile, which means,

> *"…being able to get the balance right between creating the right kind of environment for a change to happen and protecting the interests that regulator is obliged to protect"* (I13 – Government).

The environment for change is created by policy certainty. Policy certainty will ensure the appropriate amount of private investment into the industry. It is expected that more policy certainty is provided in the future while at present, *"…it's not clear to me [an investor]… what my revenue stream will be because you know the kind of policies changing all the time"* (I8 – Network company). However, government interviewees did not emphasise policy certainty but consider the level of profits that private investors would receive to be more salient to private investors,

> *"…that doesn't mean that it's bad that they [private investors] are making profits … because the product of that profit and private investment invariably is pretty high investment in innovation"* (I28 – Government).

These two different approaches (policy certainty or profit for investors) to secure investment show uncertainty about how this future might be enabled.

Energy policy also needs to take the whole-system approach, as argued by interviewees in the context of many different innovations happening across different sub-systems. The whole system approach will ensure the integration of different *"technologies, services and business models in policy and so on … the whole value chain from generation through the consumption"* (I13 – Government).

The following sections detail how generation, consumption and network will look like in this future, in response to governmental decarbonisation energy policy.

5.4.1.2 Generation

Within the Generation sub-system, a mix of almost every kind of *green* generation such as offshore wind, solar and biomass is developing. The generation mix may or may not include nuclear power, onshore wind, tidal power, gas power plant, but *green* generation is expected to be *"decentralised more and more*" (I7 – Incumbent energy supplier). The development of green generation seems to be taken for granted because interviewees mentioned about these generation without any evidence.

Carbon capture and storage (CCS) is also expected to play an important role in decarbonisation in this future. This view is based on the recommendation the Committee on Climate Change carbon budget as argued by an interviewee from the government. CCS will exist together with energy flexibility in the decarbonisation agenda. CCS captures the carbon from the future unclean generation mix (e.g. gas power plant) while flexibility "*manages your demand in a way which you can align it better with renewable generation*" (I13 – Government). This combination is expected to help the UK achieve 2050 decarbonisation target.

5.4.1.3 Consumption

As described above, energy flexibility is argued to be needed in this future. Energy flexibility emerges from the transition of the UK model from *"inflexible demand, flexible generation to the other way around*" (I7 – Incumbent energy supplier). However, interviewees highlighted that it is uncertain which routes of flexibility (e.g. traditional economy 7 tariff, storage, EVs, home energy management with smart devices, demand side response) that the industry in general and energy suppliers in particular will follow. For example, an interviewee highlighted that investing in storage might be "*risky*" for some private investors (I8 – Network company) while another argued that storage can be developed *"through Electric Vehicles"* (I7 – Incumbent energy supplier). Regardless of which route of flexibility is adopted, it is expected that "*there will be a supply chain emerged to support the flexibility"* (I13 – Government), e.g., aggregators in terms of demand side flexibility. This future is expected to involve many new entrants.

Equally, digitisation was raised by interviewees as the most important element in this future which can "*enable transition"* (I13 – Government). Digitisation brings about the *"connected home"* with smart technologies such as smart meters or smart charging for EVs (I13 – Government). Smart meters are argued by an interviewee from an incumbent energy supplier to allow energy suppliers to tailor a flexible time-of-use tariff for consumers' electricity usage. Others, however, question the significance of smart meters as similar data can otherwise be collected through the internet, for example,

> *"why would I rely on smart meters … I have the internet for heaven sakes"* (I13 – Government)

Moreover, within the development of digitalisation, Blockchain technology can be developed to allow a peer-to-peer model of energy trading where a consumer can sell his/her electricity, from his/her fully charged EVs to his/her neighbour to get some price arbitrage. An interviewee considered this model as "*really interesting stuff"* (I28 – Government).

Whether a flexible time-of-use tariff or peer-to peer works depends on consumers' engagement. Consumers are expected to engage in controlling their electricity use, be aware of the price of electricity and act rationally in response to changes in price. The majority of interviewees agree that consumers are "*citizens*" in the sense that they have more *"responsible attitude to the resources*" (I7 – Incumbent energy suppliers) and acknowledge the needs for contributing to decarbonise the sector. However, in this future, consumers' behaviour may be more complex than what the industry expects. For example, consumers may want to charge their EVs whenever they want and do not care about issues that the networks may face whereas the industry hope to "*control"* consumers' charging practices by flexible electricity time-of-use tariffs (I13 – Government). Adding to the complexity of judging consumers' behaviour is the challenge of developing a flexible tariff for disadvantaged consumers, e.g. who do not have access to data/ internet. As an interviewee highlighted,

> *"You [disadvantaged consumers] take a time-of-use tariffs and you don't adjust your demand, you will end up paying more. And we are nervous about that… This must be resolved with the regulator"* (I7 – Incumbent energy supplier).

This comment emphasised the role of the regulator in consumer protection in new business models. The regulator is also expected to create a level playing field between incumbents and new entrants. Incumbents highlighted that they are treated unfair because *"the ability for new actors to cherry-pick is very significant"* (I7 – Incumbent energy supplier). For example, in the case of smart meter, a new entrant energy supplier is allowed to take on supplying electricity to a household where a smart meter has been installed by an incumbent supplier. The cost of smart-meter installation is covered by this incumbent supplier, but the new entrant arguably can take the benefit.

Despite new entrants' cherry picking, incumbent energy suppliers are confident in their position in the industry because they consider themselves more credible than new entrants due to their longevity.

> *"You would have seen a very big title this week in the media where for years, they've been saying leave the Big Six, they're rubbish, they're overpriced, their customer service has gone downhill. Now they're saying whatever you do, don't leave the Big Six because your energy*

> *supply will go bust, and will leave you with a massive headache. Now, you're getting a cheap deal and lots of risks"* (I11 – Incumbent energy supplier).

Here, the credibility or trust issue is based on the reputation and financial stability of these incumbents. As a result, interviewees in this future tend to assume rational consumers.

This future will secure places for both existing incumbents and many new entrants with good financial base. These new entrants are argued to be incumbents from oil and IT sectors e.g. Shell, Amazon and Google. These incumbents and new entrants are likely to secure their places in the electricity by merger and acquisition strategies. Some examples are highlighted by interviewees, including Engie (a French multinational utility company) acquired stakes from Kiwi power (an aggregator in energy flexibility) or Shell (an oil and gas major) bought First Utility (an energy supplier) (I12 – Energy supplier).

5.4.1.4 Distribution (Network)

In the Distribution (Network) sub-system, the changing roles of National Grid and DNOs are discussed by interviewees. With the expected development of energy flexibility, DNOs are expected to transform to DSOs and take over some regional system balancing from National Grid (I28 – Government). This role is increased partly due to the anticipated development of many local activities such as peer-to-peer trading model. However, another interviewee highlighted that the change from DNOs to DSOs is "*more of a personal opinion*" and in a "*pivot*" period (I13 – Government). As such, it is uncertain if this change will materialise in this future.

If this shift in roles materialises, National Grid as an ESO is expected to better manage the system, also with demand side flexibility although having *some* current role taken by DNOs. National Grid is anticipated to manage high volume of net flows because,

> *"the Southwest can pretty much manage itself broadly-ish, the Northeast can pretty much balance itself broadly-ish but there is, inescapably, a flow of energy from Scotland and North Sea into the Midlands and into London and that will always be the responsibility of National Grid"* (I28 – Government).

Interviewees share the view that many new markets are emerging around the operation of transmission and distribution grid in the future. Value is argued to flow to all participants, whether they are system operators, or aggregators, consumers, generator, supplier and so on, *"they should all be valuing"* (I26 – Market operator). However, the interests of these participants might be conflicted and it is expected to be resolved by designing whole-sale market rules, which *"provide a level playing field"* (I26 – Market operator) because,

> *"I believe if you have an efficient wholesale market, you will enable a more efficient retail market for you and me"* (I16 – Market operator).

While this future is characterised by uncertainty over generation mix, consumers' behaviours, equality or the large numbers of new entrants, a clear boundary between traditional generation, consumption and distribution is maintained.

5.4.2 System relationships

The prevailing relationship in this future is the co-existence of environment decarbonisation and economic growth. This relationship resonates with ecological modernisation discourse where the government is expected to ensure that private investors realise the benefits of investing in green technologies.

In order to fulfil government decarbonisation targets, the industry is expected to embrace and develop innovations in green industries such as energy flexibility time-of-use tariff (or flexible tariff). This innovation can only succeed with the engagement of consumers as argued in the previous section. Consumers are expected to be "*citizens*" who care about "*decarbonisation*". In this case, the government, the industry and consumers are expected to collaborate and enhance relationships for a single goal of decarbonisation in the future. However, it seems that such collaboration is rather an expectation of the industry than a realistic future because consumers' behaviour might be more complex and uncertain. For example, consumers may want to charge/ uncharge their EVs based on their personal needs, rather than when the system needs them to. The issue is that the majority of interviewees are not aware of such irrational behaviour of consumers.

Many relationships are expected to continue, for example, between consumers and incumbents because consumers will not trust new entrant energy suppliers (see section 5.4.1.3). As such, in this future, the relationships between conventional sub-systems generation, consumption and distribution are expected to be largely untouched. However, in this future, interviewees do not realise that demand side flexibility may start connecting these conventional sub-systems. As highlighted in the previous section, demand side flexibility (at consumption sub-system) will help the system adopt more renewables (at generation sub-system) and system operators (at distribution sub-system) secure more value, i.e. better manage the system.

5.4.3 Power

With the pressure and the legally binding target from government to reduce carbon emissions, electricity generation continues to shift to lower carbon sources. Power is exerted by the government. The industry also has significant power in this future. It provides private investment for the development of technologies and innovations, especially in a domestic context.

Equally, consumers are expected to have more control over their energy usage to enable cooperation with the industry. The development of energy flexibility through possibly development of EVs and home smart technologies will reshape consumers as more powerful actors becoming involved in shaping and delivering energy flexibility. Here, consumers are expected to have significant power in this future.

Demand side flexibility is also expected to support the system operator (National Grid) and DSOs to ensure the fundamental physics of the system, i.e. *"the electricity network needs to balance everything every second"* (I13 – Government) and as a result, to participate in decarbonisation efforts and bring values or benefits to the system. As such, system operators at national and local level are expected to have power in this future. However, the power of National Grid as a system operator will be shared by DSOs (see section 5.4.1.4). Here, the power of system operators and DSOs are constrained by the power of system's fundamental physics, i.e. structural power.

The existing power of incumbent energy suppliers remains because they have good financial foundation which can ensure security of energy supply to consumers and hence, is expected to be attractive to consumers. Similarly, incumbents from other sectors such as oil and IT, with their economic power will penetrate the electricity sector at *"enormous pace"* (I13 – Government).

5.4.4 The metaphor of energy flexibility

Energy flexibility is not the key aspect of this future but is increasingly important. Energy flexibility is considered as an added technology in generation to help the sector achieve decarbonisation targets. Similarly, on the consumption side, energy flexibility can also be achieved by adding technologies such as storage, EVs or home energy management with smart devices, or by adding an electricity tariff to consumers' bills such as the economy 7 or flexibility tariff, or by involving the penetration of new entrants such as aggregators. Within the distribution subsystem, energy flexibility will start to effect and help the system operators at national level (National Grid) and local level (DSOs) better manage the system. Therefore, energy flexibility is deemed as an element of the distribution system in particular and of each traditional sub-system in general.

5.5 FUTURE 4: CONSUMER-CENTRIC FUTURE

This future is built around the discussion and commentaries of interviewees ascribing to consumer sovereignty discourse about a new relationship between consumers and the industry. Although consumers and their power have been briefly discussed in previous futures, this future is based on a deeper restructuring of consumers status and behaviours' and expected industrial responses.

Interviewees grouped in this discourse coalition span a variety of roles in the value chain of the industry such as incumbents and new entrant energy suppliers, network companies and the regulator. These interviewees share the idea that consumers may or may not want to engage in the operation of the industry, but consumers always want to have *control* over, for example, their energy use. As such, consumers are going to play a more significant, central role in the operation of the electricity industry which, in turn, will make the industry think of different ways to satisfy consumers. Therefore, the consumer is sovereign in the sense that they exercise power explicitly or implicitly even though they do not engage. Consumers and the industry are two first components of this future. Regulation is the third key component of this future because interviewees also voiced their opinions about the change in regulation in order to support the industry to satisfy consumers and enable the requisite changes in the relationships between consumers and the industry. All three components (1) consumers (2) industry and (3) regulation are shown in Figure 5.4. These key components will replace the conventional components of the system (generation, distribution and consumption).

5.5.1 System components

Consumers are expected to behave differently in the future, and, as such, the industry will develop different strategies towards consumers. The regulator also needs develop different approaches

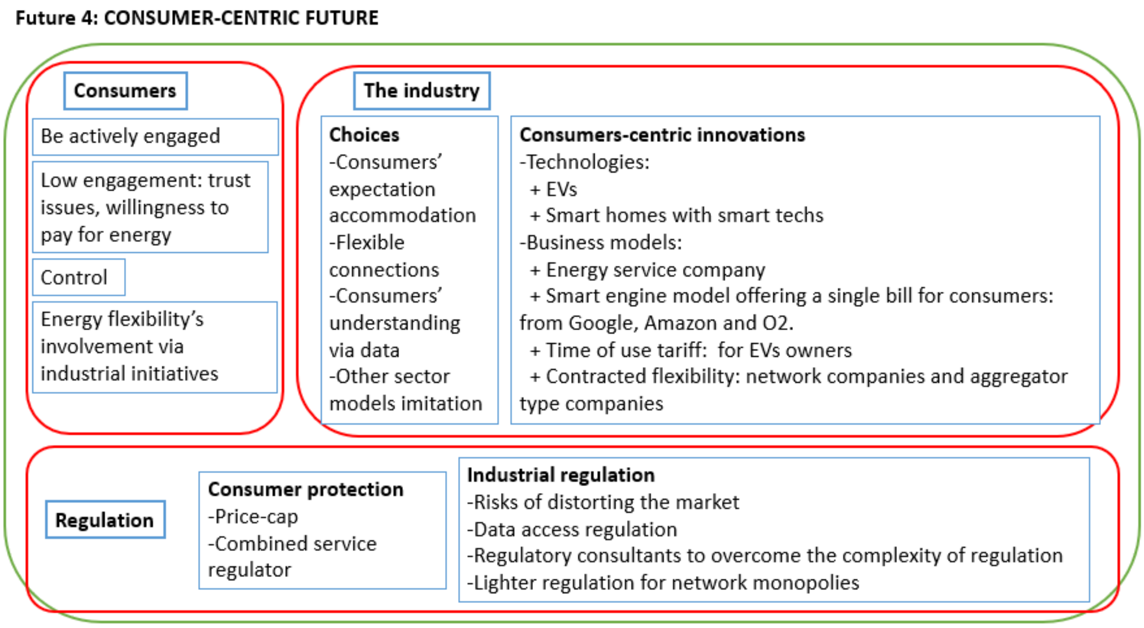


Figure 5.4: Future 4 systems map

from existing regulation. The key system components of consumers, the industry and regulation in this future are discussed below.

5.5.1.1 Consumers

There are two main views on consumer's engagement in this future. Some interviewees argued that consumers can potentially actively engage with the industry, for example, *"they start adopting smart home technologies that might give them you know the way to optimise that electricity consumption"* (I23 – Network company). Conversely, some interviewees might think that consumers, rather than willing to be part of a more integrated system, will be apathetic to their electricity use in the future. The reason is *"fundamentally energy prices are high, but people are willing to pay them"* (I10 – Energy supplier) which means that consumers will not respond to any financial incentives to participate, i.e. to change their energy use. Moreover, consumers keep *"low engagement level*" or do not want to engage because they do not trust the industry which is *"over-pricing"* (I5 – Industry commentator – regulation perspective).

Regardless of these contradictory perspectives about consumers' engagement, interviewees share an agreement that consumers are expected to have more *control* over their energy related decision making than in the past. For example, an interviewee took an example of the change from "*Town Gas to North Sea gas*" in which consumers accepted Government control, whereas "*people don't do that these days!*" (I14 – Industry commentator – network perspective). In this future, consumers will,

> *"want to control their experience. Some of that is measured in terms of controlling the price, but some of the consumers that we've worked with, once they understand the cost, they're actually willing to pay more. Others are more interested in controlling heat in their home to protect the house so they want to reduce darkness or whatever, and so that, what they like is the control they get over the deployment of heat in their home. Others want to be able to make it comfortable for their families or some like to have to be able to control the heating to prevent the debate and discussion about the thermostat settings"* (I13 – Government).

Consumers expectation is to have more *control*, rather than more *engagement* for financial incentives. Seen in this way, consumers are assumed to not follow economic rationalism behaviour. Although consumers might not want to actively engage in the industry, they are still going to play a significant role in the industry. An interviewee from an energy supplier noted that consumers can "*can start to play a role in*" energy supplier's businesses (I10). Another energy supplier suggested that DNOs should also place consumers "*at the core*" of their businesses (I12 – Energy supplier) or "*at the top*" of the system, especially with "*their [DNO's] desire to become regional system operators"* (I14 – Industry commentator – Network perspective).

Similarly, with regards to energy flexibility, consumers are expected to get involved and play a bigger role in providing demand side flexibility because, *"…the number of these [generation] technologies is inherently inflexible which basically pushes the needs of flexibility down to the customers"* (I2 – Academic). However, some expect that consumers will not care about whether energy flexibility needs their engagement, they just want to have control. Hence, "*flexibility is very much an industry challenge rather than a customer problem"* (I10 – Energy supplier). *T*he industry will be forced to change their business to take into account this consumer behaviour, but

> *"…the opportunity is that how we can engage with those customers in a way that doesn't restrict what they want because nobody wants to be restricted and you now receive instructions about what they can, and what they can't do"* (I23 – Network company).

The ultimate goal of this change is meeting decarbonisation and ensuring revenues, although these are not explicitly mentioned by interviewees. Several approaches for (1) satisfying consumers' need to have more control and (2) encouraging them to take more important roles in the sector are described in the following section.

5.5.1.2 The industry

Considering a greater role of consumers in businesses in this future, the industry will approach consumers by (1) choices or (2) consumers-centric innovations (both technology and business models).

5.5.1.2.1 Choices

Firstly, organisations are expected to offer consumers more "*choices*" to get them engaged.

> *"…we want to offer choice to customers but at the same time we are trying to integrate them and get them to help us"* (I23 – Network companies).

By offering more choices for consumers, the industry expects to not only accommodate various consumers' expectations but also let consumers exercise their decision making.

Some choices have been adopted by different organisations across the value chain. For example, different choices of smart thermostats to suit customers' different needs (I10 – Energy supplier); or enabling the "*concept of flexible connection"* (I23 – Network company) where consumers are offered choices of having a 100% capacity connection or less than 100% capacity connection with some discount.

The opportunity to offer more choices for consumers depends on how an organisation understands consumers' needs which in turn is facilitated by the availability of consumers' data. This future relies on customers allowing "*businesses to understand consumers much better and target*" (I2 – Academia), particularly actual use rather than their profile class (I10 - Energy supplier). This requires new relationships with consumers to get "*real-life*" data (I10 – Energy supplier). Various ways to build relationships in the future are suggested by interviewees. For example, organisations may use their relationship with third parties such as "*a resident liaison office…who'll actually go in and have a face-to-face conversation with the customer*" (I10 – Energy suppliers) in social housing projects or local authorities to build an understanding about consumers.

Interviewees drew examples from many other sectors where consumers have choices to further explain how *choices* should be designed. An interviewee from academia refers to the holiday and leisure sector which allows consumers to "*do peer to peer*" or "*go to a traditional website*" for booking a hotel (I2 – Academic). Another interviewee from an energy supplier used a transport example:

> *"…people didn't choose their new car based on it having a connectivity with Spotify but the next version of the car…which they choose for their needs based on…how the car looks, how they're how they're going to use it as the best vehicles for them, and then it also happens to come with Spotify as an added plus rather than being their main purchase driver"* (I10 – Energy supplier).

Future development of the electricity sector will be oriented to meet different needs of consumers using different options. In other words, consumers' needs decide the development of innovation, rather than innovation decides consumers' decisions. Seen in this way, innovations are expected to be "*consumer-centric*" in the future.

5.5.1.2.2 Consumer-centric innovations

This type of innovation in both technology and business model is aimed at the consumer wanting more control but not wanting to engage. Interviewees agree that these innovations will potentially help consumers to have more control over their decision making. Some interviewees start to recognise that these innovations can potentially disrupt the way consumers interact with the industry in the future. The following sections look at different visions from interviewees about consumer-centric innovations and examine how these innovations help consumers take control or change existing consumers' interaction with energy.

5.5.1.2.2.1 Technological innovations

A key factor in the uptake of some technological innovations is the cost of technologies e.g. cost to replace batteries in an EV (I5 – Industry commentator). However, the majority of interviewees agreed that cost of consumer-centric technologies will come down in the future as the cost of EVs is reducing (I2 – Academic) and smart home technologies will reduce their costs in 3-4 years (I23 – Network company).

Electric vehicles will be a "*consumer-centric*" innovation for consumers who want "*fun to drive"* (I2 – Academic) and "*younger generation who were more driven by environmental drivers"* (I10 – Energy supplier) and who need to commute to work. Electric vehicles will be combined in some business model innovations which are described below.

A smart home with smart technologies is also a technological innovation in the future. Smart meters are essential in this future because they will give consumers visible control over their decisions of engaging or not (I14 – Industry commentator). As one interviewee noted:

> *"I've had it [smart thermostat] only for three or four months, I'm not sure that it has saved me money yet, however what I found is that the biggest benefit that I personally take is the fact that I can remotely now control and is giving me this peace of mind that you know if I'm running out of the house in the morning and I don't, and I forget, I can remotely you know switch it off"* (I23 – Network company).

Similar smart technologies are expected to help consumers to have more control (as noted in section 5.5.1.1). However, the benefit of the smart thermostat in this example is more about lifestyle and "*nothing to do with energy"* (I23 – Network company). A smart home is expected however, gradually to become "*the easiest thing to do for your everyday life"* (I23 – Network company). Seen in this way, technologies in smart home do not change the interaction of consumers with energy. Instead, this relies on business model innovations.

5.5.1.2.2.2 Business model innovations

Beside the above technological innovations, interviewees agree that business model innovations which are "*consumer-centric*" will disrupt the current electricity sector (also see section 4.2.2.2). For example, one interviewee anticipated business model innovation is "*a bundling of products together with services"* (I2 – Academic), such as combining broadband, mobility, heat to energy and all delivered by an energy service company. In this future, the consumer will stipulate:

> *"I would like my house between 18 and 21 degrees in these times of the day, it is up to you [energy service company] of how you deliver it. So, I pay for warm, pay for comfort, pay for mobility"* (I2 – Academic).

Here, this business model innovation will potentially change the interactions between consumers and the energy industry. Consumers will have the link with these energy services companies, rather than with traditional energy suppliers and they will pay for the services that they received, rather than pay for energy per kWh.

Possible newcomers could be Google, Amazon or O2 (I5, I14 – Industry commentator), but all will offer consumers with one single bill. These organisations, instead of consumers, will "*pay my [consumers'] broadband, my home demand electricity bill, my insurance, and it's all done through a smart engine"* (I14 – Industry commentator). Consumers will have an overall *control* by asking these smart engines,

> *"Has anything happened today?*
>
> *We've changed your energy supplier, your energy supply now with such and such. Or we've, through this energy company… and your energy contract … you've saved twenty-five pounds today"* (I14 – Industry commentator with network perspective).

As such, this model will potentially not only changes the interaction of consumers with traditional energy suppliers but also provides consumers with control over their life without the need to get deeply engaged.

Similarly, choices will be offered to EV owners such as (1) time of use tariff and (2) contracted flexibility which can be considered as two business models for EV smart charging to work.

Firstly, network companies will provide price signals to energy suppliers or whoever has a direct link with consumers. These organisations can "*convert them into a tariff"* (I23 – Network company) to "*provide the right signals to consumers"* (I2 – Academic) and get some consumer segments engaged - although it is expected to be a "*really small sector of the market"* (I10 – Energy supplier).

Secondly, network companies have contracts with "*aggregator type companies*" for specific areas of network where network companies "*are willing to…pay consumers to turn down at specific times*" (I23 – Network company). In this contracting model, "a*ggregator type companies*" are expected to "*recruit consumers*" (I23 – Network companies) using options. Examples might include buying a PowerVault battery from the EDF website with a discount if consumers allow EDF to use their battery to do "*frequency response and DNO services"* (I23 – Network company). As such, "*aggregator type companies*" will give consumers a fixed "*payment*" and will help consumers manage all the other elements (I10 – Energy supplier). Although this model is currently available in the market, it is expected to become widely adopted as "*a winning-strategy*" (I10 – Energy supplier) because it fits with the expectation of consumers who want more *control*, but not more *engagement*.

5.5.1.3 Regulation

Regulation is expected to move beyond its traditional roles as *"give consumer protection whilst encouraging competition in the marketplace and secondly to enforce compliance"* (I5 – Industry commentator). These changes are explored below.

5.5.1.3.1 Consumer protection

Interviewees following consumer sovereignty discourses agreed that as more and more organisations enter the market offering consumer-centric products, consumers need to be further protected. The introduced "*price-cap*" of Ofgem (the regulator) is essential in the future to further protect consumers and is a "*direct response to the trust problem*" from the government and the regulator (I5 – Industry commentator - regulation perspective). However, another interviewee argued that there will be enough competition in retail in the future and regulation such as a price cap is unnecessary. This interviewee highlighted that "*when you start to interfere in markets…you start to get distortions in market"* (I14 – Industry commentator - network perspective). The disagreement among interviewees regarding the price cap contribute to the uncertainty of this future.

Referring to the bundle of energy service model or the penetration of Amazon, Google or O2, this interviewee went on to note about a regulator for combine services,

> *"I can imagine in the future there will be a consumer regulator that covers broadband, television, energy, shopping because the way we're interacting with these things is changing so much"* (I14 – Industry commentator).

5.5.1.3.2 Industrial regulation

Interviewees agreed that the main priority of current regulation is to ensure that consumers are protected and are able to freely switch to different energy suppliers. However, such regulation focussing too much on consumer protection may pose the risk for the industry, especially energy suppliers' new entrants,

> "…*if you're trying to drive an investment decision based on an asset that you are looking to get a 20-year might value from, then if the customer might switch away in one year, that's*

a really difficult risk profile to have. If you go and talk to regulator about kind of locking a customer to a five-year contract, that's completely not where they're looking to go with the markets" (I10 – Energy supplier).

While this is a regulatory barrier for the industry in general and energy retailers in particular, there are no suggestions about how this issue will be resolved in the future. New entrants coming into the electricity sector will also experience this and other issues such as access and availability of consumers' data. Accesses will be facilitated by smart technologies, such as a smart meter. However,

> *"This data is in theory accessible through the DCC, but at the moment, it looks a little bit exclusive about who can access it, so suppliers, network companies yes, other participants not sure at that terms of whether they have to pay"* (I2 – Academia)

It is expected that in the future, this significant regulatory barrier will be clarified but there could be further concerns about data use and ownership.

Another barrier to new entrants created by regulation is the "*sheer volume and complexity" of regulation* (I5 – Industry commentator). In order to enter and operate in the electricity market, new entrants who might not have the ability to employ experts on regulation need to fully understand such "*burdensome*" regulation (I5 – Industry commentator). Currently, there are some organisations offering regulatory consultation for these new entrants such as Utiligroup which offers a "*Supplier in a Box"* package where new entrants can get support in navigating regulation. This model is expected to further develop in this future.

In contrast to the consensus that consumer regulation will be further needed, an interviewee highlighted that there will be *"lighter regulation around monopolies, networks businesses"* (I14 – Industry commentator with network perspective) in the anticipation that network businesses will follow the model of commercial businesses. It is envisaged that,

> *"…utilities wait for trying to influence regulators and politicians and then react to the rules…whereas companies like Uber and other commercial companies look at the rules and then drive their business hard and wait for regulators to catch up… you'll see a much more aggressive investment cycle that will evolve"* (I14 – Industry commentator).

Here, becoming more aggressive commercial business, network companies may be freer in their investment decisions and do not need to face the current volume and complexity of regulation described above. The emphasis in the future of network regulation is that "*we [network companies] are incentivised to get … more utilisation out of our [the UK's] network"* (I14 – Industry commentator

– network perspective). According to this interviewee, such incentivisation should be done in a "*system approach rather than a siloed approach"* (I14 – Industry commentator). In other words, regulation should look at the changes of the system as a whole to maximise the value of the network, rather than look at resolving one single arising issue. However, other interviewees do not realise this whole system change.

Conversely, another interviewee within a network company anticipated that network companies will depend on heavy regulation in the future as they do now. This interviewee suggested that the current regulatory framework which "*rewards good performance rather than trying to set a minimum bar for services*" makes UK become *"one of the best places*" for network asset investment (I23 – Network company). Such regulatory frameworks with the next price control RIIO 2 (Revenue = Incentives + Innovation + Outputs) from 2023 is expected in future to help UK "*continue* [to be]" "*the most advanced country in terms of regulatory framework*" (I23 – Network company).

5.5.2 System relationships

In this future, traditional subsystems generation, consumption and distribution will be replaced by consumers and the industry subsystems. Interviewees expect consumers to help the sector by offering them choices, technologies or services which are consumer centric. However, the majority of interviewees do not realise that the materialisation of this new system boundary of consumers and the industry depends on whether consumers will accept these offers and if there are any other changes in system relationships. Hence, it is uncertain whether the relationships between consumers and the industry, especially between consumers and traditional energy suppliers and network companies will be tighter or not.

To be able to offer choices to consumers, some interviewees argued that in order to develop appropriate choices for consumers, understanding them is key as mentioned in section 5.5.1.2.1. As such, these interviewees, among others formulating this future, start to realise that the relationships between consumers and the industry will be tighter. An interviewee described the future link between consumers and the industry as follows:

> "*We will certainly see a more varied number of companies who have a direct link, direct relationship with the consumers, who may or may not be called suppliers"* (I2 – Academic).

This view not only suggests a closer link between consumers and the industry in this future but also anticipates that (1) energy suppliers might have *better* relationship with consumers and (2) there will be many new actors building relationships with consumers. In terms of the first, this presents a possible contradiction: energy suppliers may be unable to maintain close links with consumers because in the future, consumers are anticipated to be in touch with their energy suppliers as little as possible (I10 – Energy supplier), which means looser relationships among them. This is because they do not feel the need to engage and they do not trust their energy suppliers, mainly incumbents, who they are *"paying three hundred pounds more for nothing different"* (I5 – Industry commentator). One option for energy suppliers could be to access consumers data via consumer-facing organisations such as local authorities in social housing services (I10 – Energy supplier). However, it is uncertain if this option is useful because current energy suppliers may or may not have such relationships with these consumer-facing organisations, which means building another new form of relationships before approaching consumers.

In terms of the second expectation of new actors, it is uncertain whether consumers in the future will be more willing to have a connection with untested, new entrant energy suppliers. One interviewee starts to realise that new actors such as energy service companies will establish direct relationship with consumers and also build closer relationships with actors from other sectors, e.g. mobility. For example, there would be *"some blurring of traditional companies with even mobility companies, so … Nissan, Renault, Tesla are interested in different forms [of doing their business]"* (I2 – Academic).

New entrants from other sectors such as Amazon, Google or O2 are also envisaged,

> *"Google [will] send me an energy report every month, I get more interaction from Google than I do from N-Power, or Scottish Power where I have my electricity from, and gas from"* (I14 – Industry commentator).

These new entrants are expected to take over the relationships with consumers from traditional energy suppliers and consumers are assumed to become more willing to interact with new entrant energy suppliers,

> *"…if the utilities aren't careful, they will become a back office and somewhat isolated organisation that is basically like a second tier to Amazon or somebody else"* (I14 – Industry commentator).

This case also applies to network companies. Although these network companies are looking to promote consumers choices by providing price signals and contracted flexibility to consumers with EVs to participate in smart charging (see section 5.5.1.2.2) which may suggest tighter relationships between consumers and network companies, at least one interviewee considers the relationship to be "*a flow of data*", not a "*personal relationship*" (I14 – Industry commentator). As such, network companies' non-interaction with consumers remains the same in this future.

Regulation seems to have tighter relationship with consumers when interviewees agreed that consumer protection should be more focussed by the regulation. However, an interviewee worries about the distortion of the market, for example, when consumers protection regulation such as the price cap is in place or when consumers are allowed to freely switch energy suppliers (see section 5.5.1.3). There are also contradictory views about regulation relationships with the industry, especially with the network companies. It is uncertain of whether heavy or lighter regulation should be applied in the future.

5.5.3 Power

This future sees consumers as the main actors. According to some interviewees mentioned in section 5.5.1.1, consumers overall are more aware of the importance of their decisions and will want to take control over their decision making, regardless of whether they want to engage in the sector. As a result, the industry is expected to offer consumers more choices or more consumer-centric business models to not only satisfy consumers but also brings benefits to themselves. Here, power is assumed to be shared between consumers and the industry.

Firstly, in terms of consumers' power, interviewees highlighted that consumers have lost and will continue to lose their trust towards incumbent energy suppliers and the industry. As such, consumers will transfer their energy use to new entrant energy suppliers which then increases the number of actors participating at present and in future (I5 – Industry commentator).

Secondly, the power is also in the hands of industrial actors who are able to understand consumers and offer consumer-centric innovations. For example, the use of smart thermostats described in section 5.5.1.2.2.1 is a lifestyle control choice rather than an energy choice (I23 – Network company). Another interviewee argued that consumers do not care about flexibility – it is an industrial concern rather than a domestic issue (I10 – Energy supplier). Here, consumers are quite passive in the transition and industrial actors are active in getting consumers involved in consumer-centric innovations. Transitions consequently will be driven in the direction that industrial actors prefer and guide.

Among industrial actors, there are different groups of actors exercising their power in relations with others. A key element is

> *"...a very large number of companies quickly [come] into the marketplace to provide genuine choice and diversity for customers. And at the same time puts pressures on some of the established players to look carefully about their price and look carefully about their customer propositions"* (I5 – Industry commentator).

These new entrants (including incumbents from other sectors such as Amazon, Google, O2) exercise their power in many aspects of consumers' life in the future, "*take care*" of these aspects and become consumer-facing actors in the industry. Other actors including DNOs and energy suppliers (both new entrants and incumbents) will become the "*back-office*" and do not have direct relationship with consumers (I14 – Industry commentator) – losing their power and influential relations with consumers. Hence, power is assumed to be transferred from existing incumbents to new entrants.

Regulation or the regulator will be a key factor in resisting or enabling new power relations in this future. There is recognition that consumers will need to be protected and such protection will be more important in the future where more and more industrial actors coming into play and taking care of many, wider aspects of consumers' lives. Although the regulator is more and more important in this future, the regulator is also expected to exercise resistant power (i.e. power to resist changes) in transition as the "*sheer volume and complexity*" of regulation could create difficulties for new entrants to enter the electricity market (section 5.5.1.3.2).

5.5.4 The metaphor of energy flexibility

Energy flexibility is a metaphor in this future but not explicitly defined. It reveals various assumptions about changes in system relationships. When talking about the needs to get consumers involved in energy flexibility (section 5.5.1.1), an interviewee referred to *flexibility* as conventionally "*[generation] technologies*". It assumes that current source of flexibility which is taken from quick start-up characteristics of some power plants in generation mix will be replaced by a new source - demand side flexibility. A small number of interviewees start to realise that this new source involves the participation to some degree of consumers (i.e. the changes in relationships between consumers and the industry), dependent upon consumer behaviours. Seen in this way, demand side flexibility is expected to disrupt system relationships and ultimately constitute architectural innovation. This is at odds with arguments from interviewees describing flexibility as a business model enabling EV's smart charging in the future (section 5.5.1.2.2.2), e.g. contracted flexibility. Aggregator-type of companies will penetrate and directly help consumers manage their demand and incentivise them by "*fixed payment*". As such, flexibility is assumed to be achieved by *adding* aggregators and some financial incentives to the system.

5.6 FUTURE 5: PROSUMER-LED FUTURE

This future is rooted in an energy democracy discourse in which interviewees emphasised the new role of consumers as "prosumers" and new ways to govern these prosumers. The change from consumers to prosumers is facilitated by decentralised generation mix. The generation forms the first system component. The second system component is consumption which comprises the development of prosumer and associated elements. The third system component (distribution – network) involves the new arrangements for network and system governance. The final key section is regulation which supports these three sub-systems. These system components are mapped in Figure 5.5.

In this future, the conventional boundary between generation, distribution and consumption will still be extant, but with overlaps in the prosumer and local authorities' components. Generation and distribution sub-systems will also overlap in terms of back-up for the decentralised generation mix.

5.6.1 System components

According to interviewees, the environment (in a systems sense) is dominated by the climate change landscape. Climate change policy commitments will make the electricity sector decarbonise "*fairly rapidly*" (I16 – Government). Internally, this system consists of four main sub-systems (1) Generation, (2) Consumption, (3) Distribution – network and (4) Regulation. The following sections describe how this future will operate.

5.6.1.1 Generation

Key to this future is the generation mix. As coal power plants are decommissioned, they will be replaced in response to climate change imperatives. At the same time, decentralised renewables

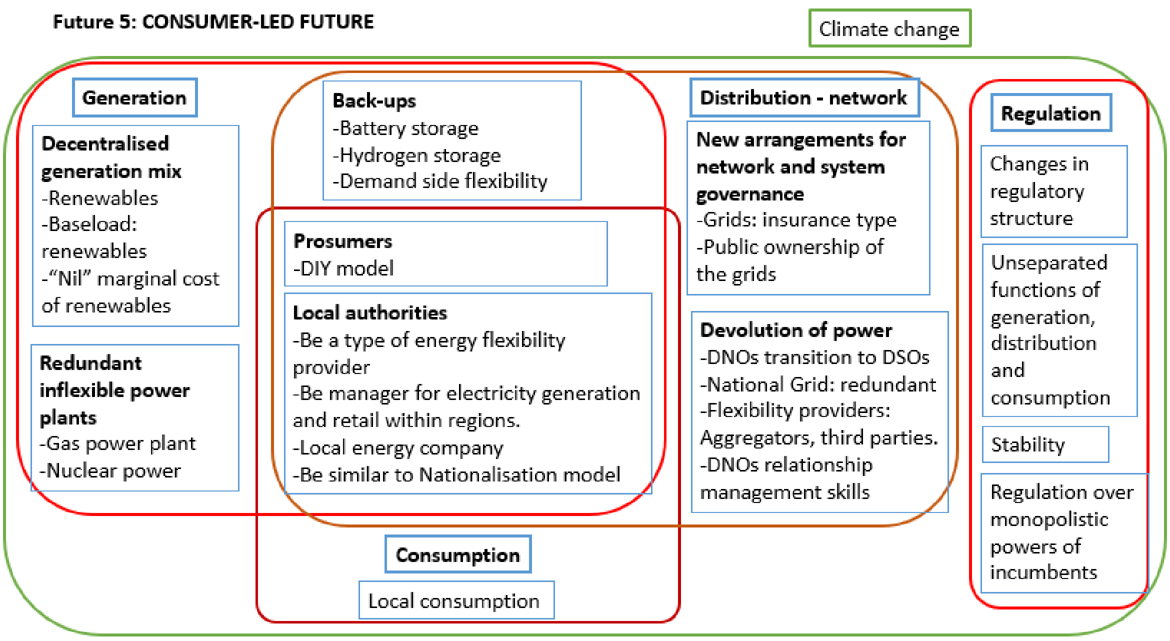


Figure 5.5: Future 5 systems map

are expected to continue to develop significantly and become the main type of generation in the future. Over the long term, renewables will become more economical than fossil fuel for electricity generation which have low investment cost and high fuel cost. Renewables, in contrast, according to interviewees, have high investment cost and minimal fuel cost and, once deployed, marginal costs start to reduce to "*nil*" (I16 – Government). Renewables will then become baseload and come to the top of the *merit order* –a way of ranking primary energy sources for electricity generation based on the running cost of the power stations (see Chapter 2). The result is that electricity generated from renewables is expected be fed into the system whenever possible.

This expectation makes gas power plants unable to operate most of the time and only contribute to electricity generation when there is limited electricity generated from renewables. As a consequence, back-up plants or investment for back-ups are needed in the future. Gas power plants, although they can bid into the system when weather conditions are poor for renewables, may become "*uneconomic*" "*stranded assets*" (I16 – Government). Hence, it will be difficult for these fossil fuel/gas plants to secure finance for further development.

Nuclear power plants, although claimed to be a decarbonised electricity generation, will not be a part of future generation mix in this future,

> *"So the whole of the system will need to be much more flexible and dispatchable which means that in the end, nuclear will probably not be on the system not because it's a bad idea that we have nuclear, [but] because it just won't fit the rest of the system anymore"* (I16 – Government)

Though interviewees agreed that gas power plants and nuclear power plants might not appear in the future generation mix, it is uncertain which type of back-up plants: battery storage or hydrogen storage or "*load shift*"/ demand side flexibility (I16 – Government) will be integrated into the system. If battery storage, for example, is integrated into the electricity system, or specifically into distribution grids, it means "*technically distributors become generators and they are not allowed to do that*" (I1 – Academia). Here, the boundary between traditional generation and distribution is blurred, which is further explored in the section about transmission and distribution.

5.6.1.2 Consumption

Before looking specifically into transmission and distribution in the future system, local consumption is a key element because it will directly impact the changes in transmission and distribution. The boundary between traditional generation and consumption is also blurred in that there is now overlap with the distribution sub-system. There are two main actors contributing to this blurring boundary: (1) prosumers and (2) local authorities.

Firstly, the potential development of prosumers, “*both a producer and a consumer*” (I1 – Interviewee) and the expected further widespread of decentralised renewables (see section 5.6.1.1), electricity is expected to “*be produced and distributed and consumed locally”* (I16 – Government). This brings traditional centralised system to a ‘local system’ with ‘local consumption’. Here, the role of transmission, distribution grids and system management are all expected to change (see further discussion in section 5.6.1.3).

A “do-it-yourself” (DIY) model might support the development of prosumer in this future. This model allows individuals to install solar panels themselves without being a certified installer. *“In Germany, the DIY market is very strong”* (I12 – Energy supplier). However, the development of prosumers is uncertain, as identified by the same interviewee: “*it's not clear at the moment exactly how far prosuming is going to feed into the system overall*” (I16 – Government).

Another actor playing an important role in this local consumption system component is a “*local authority*” who is managing electricity generation and supply within a particular region. For example, some local authorities are expected to sell electricity generated from solar panel on regional school rooftops during school holidays within their local authorities, “*which obviously is a good thing*” (I9 – Network company). In this example, local authorities are argued to become a type of energy flexibility provider for the system operator. Controlling local electricity production also allows local authorities to manage electricity supply in the future. Within a region, a local energy company managed by a local authority is expected to be established, as an interviewee highlighted,

> “*One idea which has been floated from [a city] was having a [municipal] energy company so people could actually buy their electricity from the local energy company. So you are almost moving back to municipal electricity generation. So, you know, that’s way back to the 1920s*” (I1 - Academia).

This comment shows that the local system in the future might have similar characteristics as the electricity sector in nationalisation (before privatisation). Electricity is traded within regions from local energy companies. Here, these local energy companies become involved in both traditional generation and consumption sub-systems and as a result, blur the boundaries between these sub-systems.

5.6.1.3 Distribution - network

In this future, new arrangements for transmission, distribution owners and system governance are expected.

While consumers are expected to generate and consume their own electricity, there is a concern that consumers who are unable to pro-sume may become vulnerable, as an interviewee argued,

> *"…if you've got more than a certain amount of the system covered by prosuming, then the costs of the system to those people who aren't prosuming starts to rise exponentially"* (I16 – Government).

The costs refer to the current transmission system charge (TNUoS), distribution system charge (DUoS) and balancing charge to consumers which all "*goes on consumer bills"* (I16 – Government). As prosumers may not use electricity provided via transmission and distribution grids anymore, grids may become "*an insurance or backup"* (I16 – Government). Prosumers are expected to be charged lower system charges than currently. This will mean the remaining part of system charges is shared by non-prosumers, i.e. an increased cost. As a result, it is expected that there will need to be "*a different kind of arrangement*" for transmission and distribution grids (I16 – Government).

What this arrangement will be is uncertain. One interviewee argued that both TNOs and DNOs are expected to be "*not for profit providers*" or in other words, be publicly owned, because,

> "*…sitting there as a company and making money by charging for carriage is not going to be a viable way of floating the system or for investing in it*"

Another interviewee argued that the current transmission grid owner – National Grid could be "*redundant*" (I1 – Academia) following the move to a local system. However, another interviewee argued that although local system management is expected in the future, National Grid is still needed in "*helping transmit electricity from offshore wind and interconnectors and other things*" (I17 – Government).

The development of decentralised renewables not only causes changes in generation mix (section 5.6.1.1) but also in the way the electricity system is going to be managed in the future. Traditionally, the system is balanced by matching electricity supply to electricity demand. Currently, with the increase in the amount of generation, as noted by an interviewee, "[in the past] *you would have roughly 85 points of generation to deal with whereas now [and in future] you've got about a million*" (I16 – Government), there is a mis-management in balancing the system. Interviewees argued that when renewables feed into the system, the system recognised this increase in renewables electricity supply as a decrease in electricity demand and

> *"…therefore we're [Great Britain system operator] making provision for that demand going down, but actually demand isn't going down, it's just changing in its nature"* (I16 – Government).

With such current mis-management in balancing the system, the future electricity system is expected to be balanced locally. DNOs will become "*distributed system operators*" (DSOs) and balance the system at "*the local level*" (I17 – Government). As such, the future sees not only "*decentralisation of energy*" but also "*devolution of power within energy*" (I17 – Government) as the embodiment of the energy democracy discourse. Such devolution of power also fits with the vision about the important role of local authorities described in the previous section.

The change of DNOs to DSOs involves the change in the culture of DNOs which may present problems because, as a interviewee noted,

> *"…as you move to energy flexibility, you move towards something which requires more relationship management rather than direct control and I think that could be a major problem*" (I1 – Academia).

The current arrangement of DNOs is to own and operate the distribution grids to ensure "*reliability and functionality of electricity* distribution" (I1 – Academia). DNOs are used to "*direct control*" their networks. However, in the future where DNOs take part in operating the system at the local level, it might need to integrate a higher level of flexibility, for example through storage or demand side flexibility. Here, the outcome of DNOs' operation depends on how well DNOs manage their relationships with flexibility providers, e.g., aggregators, third parties. As such, the development of this new arrangement is subject to the DNOs' abilities, expertise and skill sets.

5.6.1.4 Regulation

The move to local system future involves the interference between traditional generation, consumption and distribution, but the structure of current "*privatised but highly regulated system*" keeps the functions of these traditional elements separated. As an interviewee explained,

> *"…we do have some companies involving in retail but also involving in generation, but they have to relate to the regulation separately, they keep their two parts of the company very differently. Distribution is actually not allowed to generate and it is not allowed to sell"* (I1 – Academia).

As such, this future requires a change in current regulatory structure. There is an agreement among interviewees that it is quite hard for the current regulatory structure to change and future arrangements remain uncertain. The regulator is facing the need to change while ensuring that the changes are in "*stable manne*r" to ensure electricity supply reliability which usually "*tends to stick with original model [conventional regulatory structure] and only accept innovations that fit within* *that model*" (I1 – Academia). This interviewee highlighted that the change in regulatory structure, although is expected to occur, "*hasn't been thought through very clearly*" (I1 – Academia).

5.6.2 System relationships

While regulation remains uncertain, in this local system future, there are overlapping relationships among conventional distinct generation, distribution and consumption. In line with energy democracy discourse, prosumers tighten generation and consumption sub-systems with transmission and distribution (also see section 5.6.1.2 and 5.6.1.3) although there are different perspectives. Some interviewees recognised the development of prosumers with the potential for no relationship between electricity grids and consumers. This is because prosumers are expected to generate and consume their own electricity to the extent that transmission and distribution grids are only served as a type of electricity supply insurance. Other interviewees highlighted the role of local authorities who will serve as an energy flexibility provider aggregating electricity generated by prosumers and provide these to the system operators. Via local authorities, prosumers will have certain relationships with transmission and distribution.

Another change contributing to this overlapping relationship is from centralised generation mix to decentralised one including renewables and back-up generation e.g., battery storage. If battery storage is allowed to be owned by DNOs, i.e. placed in the distribution sub-system, distributors will become generators (see section 5.6.1.1). These overlapping relationships do not fit with the current regulatory structure of the sector and will require as yet undetermined changes.

Even so, this future still sees the hierarchy of regulation over big retailers and transmission/ distribution grid. An interviewee argued that such hierarchy of regulation is needed to manage the "*monopolistic powers*" of existing incumbents in the current privatised sector (I1 – Academia).

In contrast, an interviewee highlighted the need to bring electricity grids to public ownership to ensure transmission and distribution grid owners operate on a "*not-for-profit*" basis which allow the electricity grids to become "*insurance*" for consumers' electricity supply. Here, the relationship between the grids and the government will change from privatised grids to publicly owned grids.

5.6.3 Power

This future is characterised by prosumers' power. Prosumers' power increases with the further development of renewables and the shift from centralised system management to local management. The rise of prosumers and electricity grids as "*insurance*" will reduce the power of electricity grids' owners and the system operator. For example, National Grid may be "redundant". Here, power is assumed to be transferred from the industry to prosumers.

Within this power transfer, actors in the industry still hold some power. For example, DNOs are expected to become DSOs and take responsibility for operating the system locally (see section 5.6.1.3). Local authorities with local company energy can otherwise be in charge of local generating and selling electricity (see section 5.6.1.2).

In contrast, regulation or the regulator exercises resistant power to change in this future. The potential move to a local system with the support of some back up types for renewables-based generation such as storage or demand-side flexibility requires the blurring between these different sub-systems' boundaries. However, the current regulatory structure does not allow this arrangement.

Another resistant power to change comes from the industry actors, who have the "*mind-set of the old system and doesn't really want to move outside of it*" (I1 – Academia). Electricity is important and the sector's first priority is to ensure reliable electricity supply. Here, industrial actors (including the regulator) are worried about any disruptive change which may cause disruption in electricity supply and thus, resistant to go outside of the existing 'safe zone'.

5.6.4 The metaphor of energy flexibility

Energy *flexibility* is not mentioned much in this future but its role cannot be denied in the intermittent renewables-based system and hence, can be considered as a hidden metaphor. Energy flexibility is assumed as a back-up in generation (see section 5.6.1.1) although this metaphor conveys many different types of flexibility such as storage or demand side flexibility. Seen in this way, energy flexibility is deemed as a technology added to decentralised generation.

However, energy flexibility can potentially bring about architectural innovation. Energy flexibility is not only essential back-ups for decentralised generation but also an important element linking generation and transmission/distribution sub-systems in the future. With the expected new role of local authorities (see section 5.6.1.2), energy flexibility can be aggregated from prosumers' generation within a region to help the system operators resolve system issues. Here, energy flexibility will also change the linkage between DNOs and the industry, from direct control the network to relationship management (section 5.6.1.3).

5.7 SUMMARISING FUTURES

This section provides a summary for the above futures in terms of (1) Pathways to futures, i.e. how transitions come about, (2) Futures are messy and uncertain (3) Determinants of each future.

5.7.1 Multiple transition pathways to futures

How a transition to each future comes about are different, forming different pathways to the futures.

Future 1 is driven by market forces and market mechanism. Future 2 is engendered by the regulation and the government with evidence from research and market trials. Future 3 is led by the government with the decarbonisation agenda. Future 4 is driven by the industry trying to satisfy consumers to gain benefits. Future 5 is led by prosumers and are active in generating and consuming electricity.

5.7.2 Messy and uncertain futures

As mentioned at the beginning of Chapter 5, interviewees do not always fit in a single discourse coalition. Some interviewees also do not have a clear vision about the futures of the sector and as a result, these futures are messy. Beside this untidy discourse coalitions, futures are messy because interviewees are largely uncertain about the development of specific "system components" or innovations identified in Chapter 5. There are also contradictions in perspectives of interviewees in terms of these "system components". These uncertain and diverse views in each future are summarised in Table 5.2.

5.7.3 Differences between the five futures

This section summarises the five futures according to the four analytical components in Table 5.3. Key determinants of each future are revealed, including (1) technology and associated business models, (2) non-technological determinants (market and finance, culture, actors) and (3) regulation. Some technologies are highlighted in Bold, which play a key role in each future.

In summary, this chapter articulated five futures constructing from five discourse coalitions identified in Chapter 4: (1) 'Market-based', (2) 'Network-focussed', (3) 'Policy-driven', (4) 'Consumer-centric'; and (5) 'Prosumer-led'. Each future contains different sets of elements: system components, system relationships, power and energy flexibility. As actors do not always fit in a single coalition and agree upon these elements, futures are messy and uncertain. The following chapter provides critical reflections on these messy futures to understand how these futures may be realised and the associated changes in power and energy flexibility.

Table 5.2: Uncertain and diverse view of interviewees in each future

Future	Uncertainty of innovations and diverse view of interviewees
1	- There was no clear consensus of whether market price volatile is materialised. - Aggregators expect the development of a technology platform which opens opportunities for the blending of different traditional value pools and traditional business models while new entrant energy suppliers expect the development of a "proprietary platform" providing consumers with "flexibility price signals". - The "blending of value pools" is supported by aggregators and DNOs but is not supported by other DNOs. - EVs to grid is supported by incumbent energy suppliers while it is not supported by investors.
2	- Network companies prefer energy flexibility market trials are led by DNOs while others (e.g. from distributed business asset) prefer these trails are led by energy suppliers. - Interviewees from distributed asset businesses expected I&C consumers will be active in getting involve in energy flexibility while network companies argue that I&C consumers will not get involved directly into energy flexibility because the benefits from energy flexibility is a small revenue stream. - Network companies argue that domestic consumers are the one who control home technologies while interviewees from distributed asset businesses believe that domestic consumers do not want to control their home technologies to provide flexibility. - Network companies have diverse views of the role of energy suppliers. Some interviewees expect that traditional suppliers will become energy service provider while others believe that energy service providers will replace energy suppliers. - It is uncertain whether demand side flexibility or grid automation is going to be a dominant source of flexibility over long-term (Over short-term, demand side flexibility is expected to be dominant).
3	- Network companies expect policy certainty from the government while the government consider the level of profits that private investors would receive to be more salient to private investors. - The development of green generation is taken for granted rather than being supported by strong arguments - It is uncertain of which routes of flexibility will be followed by the industry - It is uncertain of whether the change from DNOs to DSOs is materialise in the future - Consumers are expected to be "citizens" and embrace the changes to decarbonisation of the government and the industry but consumers' behaviour might be complex and uncertain
4	- Contradictory views about consumer's engagement: network companies believe that consumers will actively engage in the industry (e.g. by adopting smart technologies to optimise electricity consumption) while others (e.g., energy supplier or the interviewee with regulation perspective) think that consumers do not want to engage into the electricity. - Interviewees with regulation perspective think that the electricity "price-cap" is essential to protect consumers while others (e.g. the interviewee with network perspective) think that price cap will distort the market; hence, is not needed. - It is uncertain whether consumers in the future will be willing to have a connection with untested new energy suppliers. - It is uncertain whether heavy or lighter regulation should be applied to network companies. Interviewees with network perspective from the industry support lighter regulation while interviewees from network companies think that heavy regulation should continue.
5	- It is uncertain which type of back-up plants: battery storage or hydrogen storage or demand side flexibility will be integrated into the system. - New arrangements for transmission and distribution grids are uncertain. TNOs and DNOs might be publicly owned. National Grid might be redundant as argued by interviewees from academia or take part in interconnection for offshore winds as argued by another interviewee from the government. The transition of DNOs to DSOs is subject to DNOs ability such as how well DNOs manage their relationships with flexibility providers. - It is uncertain how regulation will change even though there is recognition of unsuitable elements to this future such as the regulatory structure which separates conventional generation, consumption and distribution.

Table 5.3: Differences between the five futures

Analytical components	Determinants		Future 1 Market-based	Future 2 Network-focussed	Future 3 Policy-driven	Future 4 Consumer-centric	Future 5 Prosumer-led
1. System components	Key technologies (and business model associated with these technologies)		Smart meters. **Data and digitisation.** EVs V2G and smart charging. **Technology platform for DSF.** **Flexibility ToU tariff for DSF.** Platforms smart phones apps. Home autonomous technologies. Largescale battery storage and EVs charging assets.	Smart meters. **Data and digitisation.** EVs. **Smart grids** **LV monitoring.** **Automation technologies.** **Sensors.** **Flexibility platforms for DSF.** Storage. PVs. Heat pumps. Home energy management system. **DNO-led DSF.** **DSOs and ESOs cooperation.**	Smart meters. **Data and digitisation.** EVs. **A mix of generation technologies** (gas, nuclear, solar, wind…). CCS. Economy 7 tariff. Storage. EVs. Home energy management with smart devices. "Connected home" with smart technologies. **Flexible ToU tariff** for DSF. Blockchain and peer to peer trading.	Smart meters. **Data and digitisation.** EVs and smart charging: ToU for EV owners and contracted flexibility. Smart home with smart technologies. **Consumers-centric technologies and BIs.** **Energy service company.** **Smart engine model from incumbents from other (IT) sectors such as Google, Amazon, O2.**	Data and digitisation. EVs. **Decentralised generation mix: renewables.** **Back-ups: battery storage, hydrogen storage, DSF.** Do-it-yourself model. **Local authorities and local energy company to provide DSF.** **DNOs to DSOs.** **National Grid: redundant.** Flexibility providers: aggregators, 3rd parties
	Non-technological determinants	Market and finance	Efficient price discovery process	Successful market trials	Private investment. Value to all market participants		
		Culture		Time and resource costs. DNOs skills and traditional mindset. Contract design.			
		Actors	Businesses with new technologies	DSF providers: consumers, aggregators, energy service providers, energy suppliers DNOs to DSOs	Government, the industry (mainly incumbents) and consumers	Consumers and the industry who focus on consumers. Incumbents from other (IT) sectors: Google, AMZ, O2.	Prosumers. Local authorities

Analytical components	Determinants		Future 1 Market-based	Future 2 Network-focussed	Future 3 Policy-driven	Future 4 Consumer-centric	Future 5 Prosumer-led
	Regulation		Less intervention from regulation into the market.	More intervention and incentivise the new way of operating of DNOs (TOTEX, RIIO). Support network construction and investment.	Government needs decarbonisation agenda in energy policy. Governmental initiatives and funding. Principle-based and agile policy. Regulator needs to protect disadvantaged consumers and ensure a level playing field (better whole-sale market rules).	More consumers protection regulation. Lighter regulation for network monopolies. Ensure data access regulation.	Regulation changes in structures, i.e. separated functions of generation, distribution and consumption. Remain regulation over monopolistic powers of incumbents. Public ownership of the grids.
2. System relationships			Technologies blur the conventional boundary of generation, distribution and consumption. More competition between different businesses and new relationships between new entrants and energy consumers are established.	The system boundary is redrawn around network companies with the development of DSF and grid automation. Tighter relationship between DNOs and the system operator.	The system relationships remain largely unchanged.	The industry is building and will have closer relationships with consumers. It is uncertain whether consumers will have better relationship with energy suppliers or have new relationships with new actors (Tesla, Nissan, Amazon, Google, O2).	Conventional sub-systems exist but with some overlaps in terms of prosumers (producers and consumers of electricity) and local authorities (energy flexibility providers).
3. Power			Power is assumed to be transferred from the regulator to market actors.	Power is assumed to be in the hand of the government, regulator, experts and industry actors. The government uses the evidence from research and market trials to steer industry development.	Power is assumed to be in the hand of the government and the industry. The government develops an industrial strategy which is both clean and driven by economic imperatives.	Power is assumed to be shared by consumers and the industry who can offer choices for consumers and develop consumer-centric innovations	Power is assumed to be in the hand of prosumers and local authorities.

Analytical components	Determinants		Future 1 Market-based	Future 2 Network-focussed	Future 3 Policy-driven	Future 4 Consumer-centric	Future 5 Prosumer-led
				DSOs and ESO share power.	The industry provides private investment for technology development.		
4. The metaphor of energy flexibility (EF)			EF is framed as a market aspect and can be achieved by ToU tariff or technology platform which connects providers and users of EF	EF is considered as a technical issue of the network, i.e. transmission network balancing or local grid constraints management.	EF is expected to be achieved by adding technologies/elements to the system such as storage, EVs, smart home technologies, Economy 7 tariff, flexibility tariff and aggregators.	EF involves a change from conventional generation technologies to demand side flexibility. EF is assumed to be achieved by adding aggregators and financial incentives to the system.	EF is deemed as a type of back-up for a renewables-based generation which includes battery storage, hydrogen storage and demand side flexibility.

CHAPTER 6 DISCUSSION

6.1 INTRODUCTION

This chapter discusses the research findings presented in Chapter 4 and 5 in light of the literature reviewed in Chapter 2.

This chapter firstly critically reflects on the futures identified in Chapter 5 in relation to the futures in literatures. After that, this chapter discusses how these futures may be realised which consequently reveals the feasibility of these futures (i.e. considers the likelihood of these futures based on interviewees' comments and literature). These discussions on futures reveal key assumptions of the sector about the ontological nature of transitions and dominant future making practices in the sector. This chapter then discusses these with the literature.

The transitions of GB's electricity sector to these futures are embedded in transitions research. Here, the study uses the concepts from transitions research including the MLP, architectural innovation, whole system analysis, discourses and power. Critical reflections on the usefulness of these concepts are also discussed as a key contribution of this study to transitions research.

This chapter closes by discussing energy flexibility and how it can be realised.

6.2 CRITICAL REFLECTIONS ON FUTURES OF GB'S ELECTRICITY SECTOR

This section provides critical reflections of the possible futures of GB's electricity sector. Each future presented in Chapter 5 is messy which is at odds with the *tidy* futures in the transitions research and the electricity industry literature. The five futures identified in Chapter 5 are socially constructed and performative by the rhetorical interactions of actors, which resonates with several literatures concerned with futures (e.g. Urry, 2016; Oomen *et al.*, 2021). However, empirically based studies of future pathways in the context of transition management (e.g. Geels *et al.*, 2020; Rogge *et al.*, 2020) tend to overlook such interactions and complexities. Thus, these reflections suggest a different, more nuanced understanding of futures are needed in transition management. These reflections are discussed below.

The findings presented in section 5.7.1 show that there are multiple transition pathways to low carbon futures of GB's electricity sector as resonating with the literatures. The notion of pathways has been increasingly used by a wide range of constituencies including research scholars and governmental bodies as a way to frame the challenges of transitions to low carbon futures

(Wiseman *et al.*, 2013; Wise *et al.*, 2014; Rosenbloom, 2017). Multiple typologies of pathways have been developed by different scholars (Smith *et al.*, 2005; Geels and Schot, 2007). Moreover, multiple empirical transition pathways to different futures have been elaborated from both academia (c.f. Shackley and Green, 2007; Verbong and Geels, 2010; Foxon, 2013; Roby and Dibb, 2019; Rogge *et al.*, 2020) and the electricity industry (c.f. National Grid - Future Energy Scenarios (2019b), Energy UK - The Future of Energy (2019), Energy Networks Association - Networks Future Worlds (2018), Shell - Sky Scenario (2018), Committee on Climate Change - Power sector scenarios for the fifth carbon budget (2015a)).

However, being at odds with the literatures from both transitions research and the industry, five futures identified in Chapter 5 are messy. Such messiness comes from (1) untidy discourse coalitions (2) the unclear vision of interviewees about specific system components/ innovations, (3) the contradictions in perspectives of interviewees about some system components/ innovations (summarised in section 5.7.2).

In contrast, the multiple transition pathways in the literature suggest more tidy futures, i.e. do not feature interactions of actors. For example, Foxon (2013) neatly placed actors with the same interests into specific future pathways which then made these future pathways tidy. Similarly, Geels et al (2020) and Rogge et al (2020) elaborated future pathways of Germany's and GB's electricity sector, respectively, taking into account the interactions of actors in the past and present (not in the future). These interactions were then addressed in these studies to develop two neat future pathways: A - led by incumbents with incumbent large-scale low carbon technologies and B - led by new entrants with smaller-scale low carbon technologies. Here, transitions research literatures fail to fully capture how messy the futures are, although emphasising the uncertainty and open-endedness of futures emerging from the interaction of multiple actors:

> *"Transitions emerge through interactions among multiple actors, including businesses, users, scientific communities, policymakers, social movements and interest groups. They are evolutionary processes, meaning that they are typically based on searching, experimenting, reflecting and learning. They also depend critically on interpretations and social acceptance. Transitions are therefore fundamentally uncertain and open-ended."* (Geels *et al.*, 2019, p.8)

Similar to transitions research, the outcomes of the futures in the industry and government body literature are also tidy. For example, the Committee on Climate Change (CCC, 2015a) identified a list of technologies needed to achieve specific amounts of carbon emissions. National Grid (2019b) detailed the maximum potential of percentages of some technologies such as electricity generation, storage, gas supplies or hydrogen in its future scenarios. The futures presented in these literatures are tidy and are clearly defined in the sense that each technology/ business model or component can be neatly fitted in a future, without any disagreement. Conversely, the futures articulated in Chapter 5 present some dominant system components of each future but some with diverse views of interviewees. It means that it is uncertain of which components will dominate in the future.

Furthermore, the timeframe for transition in these literatures are set from 2030-2050 with an exceptional one with the timeframe of 2070 (Shell, 2018). In contrast, the findings (section 4.3) shows that there is no consistency in interviewees' perspectives about the timeframe for transitions, or innovations. Rather, the timeframe depends on disruptive events or the changes in consumers' behaviours, i.e. are shaped by context. In other words, the timeframe of transition is also subject to uncertainty.

However, the industry literature fail to recognise such uncertainty *within* each scenario. These scenarios are *tidy* which reveals the industrial belief in pre-defined transition goals which can be managed, planned and delivered. Nevertheless, transition management should be based on process, rather the goal of transition (Rotmans *et al.*, 2001). Seen in this way, setting a goal for transition might be needed but such goals are able to change and are replaced as transitions unfold. Therefore, the belief in tidy futures of the industry may hinder the effectiveness of GB's electricity sector's transition management. This insight from transition management suggests that a shift in the expectations of the electricity sector to a more nuanced and complex view of planning and transition management is needed. Rather than thinking of a pre-defined outcome (i.e. a transition goal) by following a transition pathway, transition of the sector should be understood as socially constructed rather than linear and emerging rather than pre-defined as a result of the interactions of different actor groups and other system components.

The findings about the discourse coalitions in Chapter 4 and the five futures in Chapter 5 suggest that futures are socially constructed and performative. The five futures are socially constructed in the sense that they emerge from actor interactions in GB's electricity industry (industrial actors) who draw on various discourses to construct and debate futures. These futures are socially performative because industrial actors contextualise these futures within meaningful stories, which ultimately shape and coordinate social actions (e.g. discourse, planning, persuasion) in the present. For example, Future 1 was constructed by actors holding a belief in economic rationalism. These actors are situated in various organisations (e.g. an aggregator, supplier, network company) but this study revealed that they shared the same belief in the role of market mechanism in achieving transitions. They rhetorically constructed Future 1 with stories about drivers for changes such as increasing market price volatility and complexity; about future system components, including the technology platform, flexibility time-of-use tariff; and about certain solutions such as an efficient price discovery process and less intervention from regulation. Industrial actors constructed these stories about the future to persuade other actors that futures are driven and will be materialised in accordance with Future 1. As such, they hoped to make other actors believe in the importance of market and behave rationally following economic incentives and to direct other actors' support towards their preferred components in Future 1.

These findings further confirm that futures are social products emerging from the rhetorical interactions between industry actors. In this way, futures provide industrial social actions with meanings and hold potential to shape the behaviours of other industrial actors in the present. These findings resonate with many literatures emphasising the social constructs and performativity of futures (e.g. Borup *et al.*, 2006; Adam, 2011; Urry, 2016; Tutton, 2017; Groves, 2017; Oomen *et al.*, 2021). However, empirical future pathways in transitions research are often neat and clearly delineated around dominant technologies and actors (Foxon, 2013; Geels *et al.*, 2020; Rogge *et al.*, 2020) which overlooks the complexity and contingency of actor interactions. As such, these future pathways in literature fail to fully reflect the actual processes of transitions to futures and thus, they are unable to deal with the unpredictability and uncertainty of futures in transition management (Fuller and Loogma, 2009).

Futures are uncertain and as a consequence, an acknowledgement of this uncertainty by the sector and an improved understanding on how futures are realised are needed. The following section looks at realising the futures.

6.3 REALISING THE FUTURES

The findings in Chapter 5 (summarised in section 5.7.3) shows that these futures are realised via similar determinants including (1) technology and associated business models, (2) other non-technological determinants such as market, culture, consumers and (3) a regulation determinant. The dominant determinants of all futures in relation to the literatures are discussed next.

6.3.1 Technology and associated business models

Chapter 5 shows that the majority of interviewees believe that technology is a key determinant of all futures, although the expected specific dominant technology of each future varies. This finding accords with multiple literatures from the industry on the transition of electricity sector which argue for transition of electricity system by adding or changing *key* technologies, e.g. carbon capture and storage (Shell, 2018), electric vehicles (Energy Systems Catapult, 2020), nuclear power (Sepulveda, 2016). By believing that transition can proceed by *adding* new technology and/or knowledge to the *existing* electricity system, both interviewees and recent industry literature assume that moving to low carbon futures is a technological question rather than a system question. Some recent transition literature from academia challenges the utility of this assumption (c.f. Gorissen *et al.*, 2018; Geels, 2018b; Geels *et al.*, 2019; McMeekin *et al.*, 2019). Findings about other non-technological determinants from this study reinforce the idea that transition is systemic in nature because it involves the changes of innovations in not only technological aspects, but also in "*consumer practices and needs, skills and capabilities of all actors involved, infrastructures, governance, regulation, industry structure and cultural meaning of the system*" (Schot *et al.*, 2018, p.4).

The "*technology assumption"* is also at odds with a small number of interviewees who argued for a whole system approach of dealing with transitions, as presented in section 5.4.1.1. Here, a whole system in terms of an energy system involves the changes in both technology and societal aspects across the value chain of the sector. Further discussion on the whole system analysis is explored in more detail in section 6.9.

6.3.2 Non-technological determinants

Non-technological determinants including market and financial, cultural and consumer determinants are also identified as important in realising all these futures. Although the majority of interviewees considered transitions to these futures involve changes in technologies, as discussed in section 4.4.2.1, they believe that technology itself may not present a barrier to transition to low carbon futures as technological change in the electricity sector may follow trajectories of technological change in other sectors, e.g. smart phones became dominant in telecommunication. This view chimes with transition literature which suggests there are no gaps in technology and innovation which could potentially constrain transitions to low carbon electricity futures (Mazur *et al.*, 2019).

Instead, the findings from Chapter 5 show that a majority of interviewees argued that non-technological determinants may hinder transitions to low carbon futures, reinforcing the findings from Chapter 4 (section 4.4.2). The findings from Chapter 4 show a wide range of non-technological barriers to transition including the cost of technology, financial incentives, subsidy, traditional mindset and skill sets of organisations, consumer-related barrier, the availability of information and market design barriers. Removing these non-technological barriers is essential for the sector to transition to a low carbon future. This argument accords with literature aiming to provide policy makers with practical recommendations (Foxon *et al.*, 2005; Engelken *et al.*, 2016; Ofgem, 2016; Energy UK, 2019; CCC, 2019). Seen in this way, transition appears as a linear process which can be manageable and controllable. Nevertheless, some authors challenge the utility of this assumption.

Mitchell (2008) argued that the current political governance of the sector considers the development of innovations as a linear process and hence, overlooks the actual process of innovation and/or transition. Building on this, literature in transitions research (Geels *et al.*, 2019; Köhler *et al.*, 2019) highlighted, as noted above, that transition processes are an open-ended, complex and non-linear processes which emerge through the interactions among multiple actors including businesses, consumers and policy makers – i.e. non-technological determinants.

6.3.3 Regulation determinant

Regulation is another key determinant which is identified from the findings in Chapter 4 and 5. Table 5.3 identified this determinant across different futures - each requiring a change in regulation although with different degrees of changes.

In Future 2 and 3, regulation is part of the sub-systems and varies in scope to accommodate the changes of other elements (e.g. technologies) of the sector. For example, the regulator is expected to incentivise DNOs to opt for demand side flexibility option in Future 2, or to create a level playing field for incumbents and new entrants in Future 3. In Future 4, regulation plays a more important role in transition. It is a separate sub-system which "*may experience [undergo] relatively autonomous distinctive change processes*" (McMeekin *et al.*, 2019). However, regulatory changes in Future 2, 3 and 4 do not involve changes in the structure of regulation itself, i.e. it keeps the relationships between the three conventional generation, network and consumption sub-systems largely untouched. As the regulatory structure remains untouched, it is therefore assumed as a barrier to transition and need to be overcome.

Such views are inconsistent with the view of regulatory changes in Future 1 and 5, where, in the view of these discourse coalitions, the whole structure of regulation needs to be transformed. The views of regulatory structural change in Future 1 and 5 resonates with very recent literature on transition (Geels *et al.*, 2019; McMeekin *et al.*, 2019) where regulation is understood as part of the system and itself needs to be transformed, not '*overcome*'. As such, recent literature has moved away from overcoming a single barrier, based on linear views of transition rooted in rational behaviour, towards addressing systemic challenges. Here, a whole system view of transition which realises changes in the architecture of a system is essential in transition. Further discussion on a whole system view is provided in section 6.9.

However, going beyond these key determinants which the majority of interviewees consider as barriers for transition, the findings show that it is the *interactions* among actor groups and other components of system (such as technologies and regulation) which also determines how futures are realised and consequently the feasibility of these futures.

6.4 THE FEASIBILITY OF THE FUTURES

Discussing the feasibility of the five futures identified in Chapter 5 is important to explore the practical implications of these futures for the industry. There is a variety of conditions influencing the feasibility of futures, such as the maturity of technologies, infrastructure, economic implications, social acceptance of technologies, political feasibility and interactions with other societal objectives (Loftus *et al.*, 2015; Turnheim and Nykvist, 2019). Among them, social acceptance of technologies and political feasibility are used to discuss the feasibility of futures in this section. "*Social acceptance*" encompasses "*issues, controversies, or anxieties with the expected deployment and use of any particular option*" (Turnheim and Nykvist, 2019, p.780). In this study, "*social acceptance*" implies industrial acceptance (i.e. whether an option is accepted by the industry, rather than by the whole society). "*Political feasibility*" is "*the likelihood of decisions supporting a particular path to become implemented*" (Turnheim and Nykvist, 2019, p.781). Social acceptance and political feasibility are chosen because they are crucial in determining the overall feasibility of futures (Turnheim and Nykvist, 2019; Geels *et al.*, 2020). They are shaped by social interactions (Geels *et al.*, 2020), or more specifically by the interactions of industrial actors in the context of GB's electricity sector. The feasibility of each future is discussed in turn below.

6.4.1 Feasibility of Future 1

This section examines the feasibility of Future 1 in terms of two main components of Future 1 which are (1) the "*technology platform*" where different value pools/ market (balancing ancillary market, wholesale market and local constraint management market) can be blended and (2) less intervention from regulation. This examination suggests that Future 1 is unlikely to be feasible.

Firstly, Future 1 shows that with the development of the technology platform, real-time markets for flexibility will emerge and allow flexibility to be allocated to the users of flexibility who value it the most. In other words, value can be *stacked* in this future. These findings accord with one industrial report about making sense of market trends (Elexon, 2015), which identifies that the most beneficial option would be bringing all market actors with interests in flexibility into one "*central market platform*". The idea of one central market platform is similar to the technology platform in Future 1. However, the development of the central market platform is a costly option and needs complex intervention (Elexon, 2015). As a result, Future 1 may not be socially feasible.

The recommendation of one technology platform is at odds with the regulator and government which are supporting the development of many different platforms for energy flexibility rather than a single platform (Ofgem, 2015c; BEIS and Ofgem, 2018; Ofgem, 2019a). The main function for the single technology platform in Future 1 is dispatching while Ofgem distinguishes several kinds of tasks for flexibility platforms including coordination, procurement, dispatch and control, platform transaction settlement, platform market services and analytics and feeding (Ofgem, 2019a, p.9). As such, Future 1 overlooks the importance of different types of platforms in the future and may not receive support from the regulator and government.

Moreover, interviewees with a network perspective express contested views about whether DNOs are able to get the energy flexibility that they need by participating in this technology platform (i.e. depending on markets), which may threaten the reliability of the network. As a result, this future may not be accepted by DNOs.

Secondly, Future 1 is also characterised by less intervention from regulation into the electricity market. However, the existing literature challenges the utility of this approach. The electricity sector is constrained by a "*highly interventionist*" or "*regulatory state paradigm*" that is difficult for it to change (Helm, 2014; Mitchell, 2008). Although Amber Rudd's speech (DECC, 2015a) expressed the intention of the government to be less interventionist in the market, some recent reviews from the regulator Ofgem (e.g. Targeted charging review (Ofgem, 2019b)) do not show any change in the level of intervention. Consequently, the idea of less regulation in Future 1 may be politically infeasible. As both the social and political feasibility of this future is questioned, Future 1 is unlikely to be realised.

6.4.2 Feasibility of Future 2

The feasibility of Future 2 is dependent on two main components: (1) smart grids and (2) DNOs-led flexibility market. The need for smart grids is emphasised in transition literature and DNOs' reports. However, the government seems not to recognise the importance of smart grids, which questions the political feasibility of Future 2. The likelihood of DNOs-led flexibility has also been undermined and challenged by diverse views of interviewees. These two points give rise to the uncertainty of the feasibility of Future 2.

Firstly, the main technologies in Future 2 are smart grids. Publications from both DNOs and academia highlight the significance of smart grids for the future of network as well as the reliability of supply (c.f. McMeekin *et al.*, 2019; Expert Group 3 - Smart grid task force, 2015; Connor *et al.*, 2018; Cook *et al.*, 2015; Hall and Foxon, 2014; Hiteva and Watson, 2019; ENA, 2018). Literature also highlights the uncertainty and risk for smart grid development (Connor *et al.*, 2018). However, government energy policy such as the Clean Growth Strategy (BEIS, 2017) and the Progress Update on Smart Systems and Flexibility Plan (BEIS and Ofgem, 2018) discussed the importance of smart meters and smart charging rather than smart grids. The lack of government support could hamper the industry investment in smart grids, and could therefore render Future 2 difficult to realise.

Secondly, one of the main features of Future 2 is the development of DNO-led demand side flexibility. DNOs in this future seem to be very positive about the development of flexibility, although acknowledging that futures will depend on technologies, providers of flexibility, organisational culture and the design of the contract. It is anticipated that other markets for energy flexibility which are not led by DNOs may be needed, e.g. the Cornwall Local Energy Market Trial run by Centrica - an incumbent energy supplier (2018) or real-time markets run by new entrants as proposed in Future 1. Led by other actors, these markets may reduce the social acceptance of DNO-led demand side flexibility markets. Hence, the feasibility of Future 2, reliant on smart grids and a leading role for DNOs, is uncertain.

6.4.3 Feasibility of Future 3

Compared to Future 1 and 2, Future 3 is more likely to occur because (1) it conforms to the current existing energy policy; and (2) it may be more acceptable to a greater number of industrial actors.

Firstly, in Future 3, changes are driven by the government decarbonisation energy policy. This is set out in the most recent high level policy document for Britain's low carbon future – The Clean Growth Strategy (BEIS, 2017). This means Future 3 is likely to be supported by the government and thus is more politically feasible than other futures.

Secondly, the findings of the leading role of the government in Future 3 and of energy policy in Chapter 4 (section 4.5.2) reveal the government has been criticised by some industrial actors despite the overall agreement about the importance of the policy. Critiques centre on the government's lack of a long-term view (of the network assets needed) in the future which may create uncertainty, especially for the investor community. Interviewees with investor perspectives are also uncertain about the investment signals that they can act upon while the government seems to not have a clear view on the level of profits that investment may generate, e.g. in the case of battery storage. Moreover, the government is criticised for creating uncertainty due to sudden changes in policy and associated regulation, e.g. the case of the Capacity Market has been stopped without notice. These criticisms from industrial actors - who are expected to embrace changes from governmental policy in Future 3 - might hamper transitions to Future 3. However, despite these criticisms, it seems that the industry is following policy signals for planning. It means that the leading role of the government in transitions is likely to be accepted by industrial actors. For example, in the case of Carbon capture and storage (CCS), CCS demonstration projects run by the industry were suspended shortly after the government halted £1bn investment fund for CCS without notice in Nov 2015 (Kapetaki *et al.*, 2017).

Moreover, the regulator is expected to develop a level playing field for multiple innovations and multiple actors in Future 3. It means that Future 3 can accommodate the interests of both incumbents and new entrants, compared to other futures. For example, Future 1 favours new entrants because incumbents without new technologies may become "*losers*". Future 2 favours incumbents because new entrants without good financial foundation may become "*losers*" in Future 2. Therefore, Future 3 is more acceptable to a greater number of industrial actors.

However, the architecture of the sector in Future 3 remains largely intact and energy flexibility is assumed to be a technological question, with technologies added to sub-systems as necessary. This assumption does not resonate with transitions research which recognised the needs of transitions at a system level (Mitchell, 2008; Geels *et al.*, 2019; McMeekin *et al.*, 2019). This may create difficulty for the sector to plan for transitioning to this future. Further discussion on the needs to understand transitions at a system level will be detailed in section 6.9 and 6.12.

6.4.4 Feasibility of Future 4

The feasibility of Future 4 hinges on two main components: (1) the emergence of consumer sovereignty and (2) the penetration of actors from other sectors such as Google and Amazon into the energy sector. Although this future is supported in the literature, the feasibility of Future 4 can be questioned as it is based on contested view of how consumers behave. This section examines these elements.

Firstly, Future 4 can accommodate a variety of consumers behaviours and is embraced by some recent industrial and academic literatures (Sandys *et al.*, 2018; Menges, 2003; Hamwi and Lizarralde, 2018; Quiggin and Froggatt, 2017). These literatures place consumers at the heart of energy system where industrial changes move towards consumer sovereignty and suggest some consumer-centric technologies and business models. Secondly, Future 4 is characterised by the penetration of technologies and business models of actors from other sectors such as Google and Amazon in the technology sectors which *help* consumers. For example, Google acquired NEST, a smart home company (Savenije, 2014) and Amazon launched Amazon Echo, a voice-activated speaker (Lorenzetti, 2014) which demonstrate their interests in smart home in energy sector. Google and Amazon's move towards the energy sector is consistent with the development of technologies and digitisation in this future and predicted by Helm (2017). Therefore, Future 4 may be widely accepted by actors working on energy research.

However, Future 4 faces controversies among industrial actors. Some interviewees assumed that consumers act rationally following economic incentives, while others disagreed with this assumption. Such disagreement means the social acceptance and thus, the feasibility of Future 4 is questionable.

6.4.5 Feasibility of Future 5

Future 5 is unlikely to be realised because (1) the proposal for bringing grids back to public ownership might face industrial opposition and (2) the proposal to change the regulatory structure is not easy to implement given that there is no clear view about how this will be done.

Firstly, the main feature suggested by supporters of Future 5 is the move to public ownership of the grids. However, this view is opposed by other interviewees such as one interviewee following ecological modernisation in Future 3 who argued that being in public domain may mean that there would be no incentives and motivation for network innovations. The vision of public ownership is supported by the Labour Party (2017) but it is likely to face industrial opposition (e.g. from National Grid which is a private company). There is also considerable uncertainty about how the move to public ownership would actually be achieved and at what cost (Inman, 2019). Thus, Future 5 may not be socially acceptable.

Secondly, interviewees supporting Future 5 highlighted the uncertainty in whether the regulation might change due to the inertia within the regulator itself as well as the uncertainty of the scope and format of the future regulatory framework. One concern raised in this future is about whether distribution grids can own storage. Future 5 requires the blurring of generation, distribution and consumption sub-systems in order for DNOs to generate electricity from distribution grids-connected storage. However, Ofgem (2018) announced the decision that DNOs are unable to own storage, which currently further undermines the political feasibility of Future 5.

In summary, this section reflected on futures with diverse views of interviewees and compared these with academic and industry literature (some at policy and regulatory level) to argue that Future 3 seems to be more feasible than other futures because it conforms to the current existing energy policy and may be more acceptable to industrial actors.

The critical reflections on futures, how futures are realised and the feasibility of futures reveal established knowledge of the industry on the nature of transitions. The following section hence discusses these knowledge (i.e. ontologies).

6.5 ONTOLOGY

This section discusses ontology of GB's electricity sector in terms of transition. Here, ontology refers to the assumptions about the nature of the world (Stainton-Rogers, 2006) (i.e. nature of transitions of the sector). The findings presented in Chapter 4 and 5 show that a number of interviewees in the sector assumed that (1) the industry (including consumers) acts rationally as summarised in section 4.2.4 (2) transition can occur by adding technologies or knowledge to the existing system as discussed in section 6.3.1 (3) transition can proceed by removing barriers as discussed in section 6.3.2 and (4) a pre-defined goal of transition is needed to steer transition as discussed in section 6.2. These assumptions reveal that the dominant ontology of GB's electricity is realism. These four assumptions are at odds with much of literature as detailed below.

Such assumptions of the majority of interviewees are relevant to the main features of realism discussed in section 3.2.2. Firstly, according to the realist view, human beings are purposive actors who have ideas about the world and attach meanings to events. Human beings are assumed to act economically rationally: with an incentive in financial benefit, humans will act towards such benefit. This assumption of rational choice is well established in economic theory to understand individual decision making from a realist view (Lipsey and Chrystal, 2015). However, Mitchell (2008, p.210) argued that,

> *"In general, in market economies, price is the most used basis of choice. But in a complex world, where decisions are often made from the rational perspective of the individual (or irrational from the point of economics); where there are market failures; and where factors other than economics are important to outcomes, then other means of stimulating technology development or a paradigm (structural) shift to a sustainable energy future are not only necessary but appropriate"*

Mitchell is a reminder that human behaviour is not economically rational. Yet, the current governance of GB's electricity sector while it continues to underestimate human irrational behaviour may be unable to effectively transition to low carbon futures.

Realism also focusses on explaining how mechanisms and structures produce phenomena and events (Robson and McCartan, 2016). As such, realists pay attention to facilitating transitions by adding technologies or knowledge to the system (e.g. EVs, smart meters, flexibility time of use tariff) or removing barriers to transition (e.g. technological, financial, cultural, consumer, information, market and regulatory barriers). Here, innovations and transition are deemed to be linear processes moving towards a pre-defined goal of futures which might be, for example, lower carbon. This assumption reveals an engineering perspective of GB's electricity sector which looks to engineer the transitions of GB's electricity sector. As innovations are argued to be non-linear in transitions research literature (i.e. the outcomes of innovations may be not as wanted), the dominant ontology may constrain the development of system innovations and transitions of the electricity system itself (Berkhout, 2002; Berkhout *et al.*, 2004; Shove and Walker, 2007; Guy and Shove, 2000; Kern and Smith, 2008; Mitchell, 2008).

Finally, with regard to pre-defined goals of futures such as decarbonisation or flexibility as argued by interviewees (section 4.6), the majority of interviewees assumed that a certain landscape such as government policy is needed to enable actors to progress towards transition. Hence, the purpose of a pre-defined goal for transition is to provide policy makers and planners with a clear steer on the direction of transitions. These findings accord with some industry literature such as the Fifth Carbon Budget (CCC, 2015b) and Roadmap for flexibility services to 2030 (Shakoor *et al.*, 2017). Such literature provides some certainty for those operating GB's electricity sector, but some interviewees argued that actors are learning to work under condition of uncertainty. This argument is in line with literature which suggested that the complexity and uncertainty of transitions mean that the futures are not simply planned (Hajer *et al.*, 2015; Geels *et al.*, 2019).

Although realism is evidently the dominant narratives of GB's electricity sector, this ontological position has little resonance with the transition literature. The MLP, an established framework to study and manage transitions, although can arguably accommodate realism, is founded from constructionism and structuralism (Geels, 2010; 2020). As such, realism only offers limited insights into transitions research (see section 2.4.1.4). Therefore, there is some inconsistency between the knowledge being used in the electricity sector to determine key steps of transitions with the ontologies of transition in literature.

The prevalent realist ontology in the sector is also at odds with a small number of interviewees who claim that transitions are non-linear, and consumers do not act economically rationally. For example, some interviewees from various groups such as a new entrant, trade association and consultancy firm were of the view that there is hardly any price incentive that is able to impact consumers' behaviour. As Mitchell noted,

> *"…if humans consume and behave in ways which do not fit with rational economic choices, then curbing energy consumption and changing behaviour is much more complex than is recognized by economic principles and requires a greater range of more sophisticated policies and regulations"* (Mitchell, 2008, p.5)

Although published before the Climate Change Act (2008), this view remains relevant because since its publication, the realist ontology dominating the electricity sector has changed little, as evidenced by interviewees' discussion. This suggests a shift in the established knowledge of the sector towards a more sophisticated understanding of transition processes is needed in order to facilitate transitions. Rather than being linear cause and effect processes with pre-defined outcomes, such as decarbonisation or flexibility, transition should be understood as being socially constructed and emergent *as a result of the interactions* of actor constituencies and other system components in the sector. As such, futures are uncertain and require innovation at the system level (architectural innovation) as well as a more nuanced and complex view of transition governance. By following social constructionism, this study has revealed the futures of the sector which are uncertain and emerge through the interactions of different actor groups as well as architectural innovation at system level.

This section discussed the need to develop a more nuanced and complex perspective of transitions in GB's electricity sector to counter the dominant realist ontology. Such an established realist ontology plays a key role in how futures are currently made. The future making practices of the future are discussed next.

6.6 RETHINKING FUTURE MAKING PRACTICES IN ENERGY SECTOR

Although not asked directly, a small number of interviewees commented on how futures are made within the GB's electricity sector, while the majority did not. The predominant future making practice identified in the findings included the use of models and economic concepts to determine the future cost-effectiveness of a technology or business model. In other practices, industrial actor inputs were sought through call for evidence, interviews and workshops to supplement modelling and understand energy demand in futures. Such *technical* exercises, which leave little room for uncertainty and an open discussion on power and politics, are often led by key actors. For example, National Grid developed Future Energy Scenarios (2019b), Energy UK elaborated The Future of Energy (2019), Energy Networks Association articulated Open Networks Future Worlds (2018), Shell endorsed Sky Scenario (2018), Committee on Climate Change published Power sector scenarios for the fifth carbon budget (2015a). These futures share the same characteristics including (1) Mixed methods based on quantitative modelling and qualitative data collection analysis for most notably stakeholder engagement, (2) Purposes: using future scenarios to plan for activities and (3) Timeframe: a pre-defined timeframe. Developed for governing and planning purposes, the futures in these publications are *clean*, *clear* and apparently relatively free of uncertainty.

Some frameworks such as the MLP are also used in transitions research and by policy makers to develop future pathways or scenarios (c.f. Foxon, 2013; Geels *et al.*, 2020; Rogge *et al.*, 2020). The MLP visualises key socio-technical elements and interactions of actors, and consequently, render transitions manageable and actionable. As such, these futures are *tidy*, as argued in section 2.3.2 and 6.2, while real-world transitions and futures are more messy and uncertain. Here, as the MLP cleans *up* these transitions and futures too much, it risks simplifying the real process of transitions and causing problems in managing transitions. Therefore, there is a need to rethink future making practices in GB's electricity sector and understand that futures cannot be controlled by modelling tasks and fixed transitions frameworks. In response to calls for a more nuanced understanding of practices for a sustainable future (Knappe *et al.*, 2019), this study uses key concepts from the MLP rather than the MLP framework itself and articulates futures by applying whole system analysis, discourse theory and power to enrich understanding of a socio-technical transition approach. The following sections provides critical reflections on several concepts in transitions research used in this study.

6.7 CRITICAL REFLECTIONS ON THE MLP

Critical reflections on the MLP show that although reconfiguration pathway of the MLP is likely to be dominant in transitions of GB's electricity section, the MLP might not be relevant in investigating futures of GB's electricity sector. These two critical reflections are explored below.

Futures 2, 3 and 5 presented in Chapter 5 feature landscape pressures and niche innovations adopted by regimes. In Future 2, expectations are that cost-benefit analysis and market trials from the regimes will demonstrate the benefits of energy flexibility to the government to bring pressure for changes to the energy network. As a result, the grid will adopt new sources of energy flexibility to resolve network constraints. In Future 3, transitions also come about due to pressures to decarbonise. Such pressures lead to changes and innovations in many sub-systems of the sector and most noticeably the development of low carbon technologies, e.g. CCS in generation, energy efficiency in consumption, network balancing at distributed level. Similarly, in Future 5, climate change creates landscape pressure on the regime which leads to the development of non-dispatchable/ intermittent renewables. Such intermittency changes the way that the system is balanced and leads to the development of a local energy system with the support of some innovations such as battery storage.

Here, how futures come about in these Futures 2, 3 and 5 is imagined in line with a reconfiguration pathway developed in the well-established typology of transition pathways by Geels and Schot (2007). According to this typology, reconfiguration pathway occurs when landscape pressure urges regimes to change. In a reconfiguration pathway, innovations in niches are conceptualised as symbiotic innovations which may be easily adopted by regimes to resolve regime problems and incumbents are likely to form alliances with new entrants (Geels and Schot, 2007; Geels *et al.*, 2016). This reflects the current merger and acquisition strategy in the industry where Shell bought First Utility (Shell, 2017) or Engie acquired stakes from Kiwi Power (Engie, 2018). This reconfiguration chimes well with recent perspectives on whole system reconfiguration (Geels *et al.*, 2015; Geels, 2018a). Such whole system reconfiguration has been applied in empirical works in transitions in the electricity sector (McMeekin *et al.*, 2019) and mobility sector (Geels, 2018b).

However, it seems that Future 1 and 4 in the findings in Chapter 5 focus on regime instability but do not recognise exogenous forces of change emanating from the landscape while all pathways in the MLP face landscape pressures. In Future 1, transitions are triggered by regime instability (i.e. market forces) created by the development of renewables and greater demand for flexibility. Such instability enables the regime to move towards more dynamic real-time markets for flexibility with the support of a technology platform. Similarly, in Future 4, transitions also occur due to regime instability created by changes in consumers' preferences and behaviours which consequently changes the way the industry treats consumers. This future is characterised by the development of some consumers-centric innovations such as the development of bundling energy services in domestic homes. These two futures are at odds with the transition pathways proposed by the MLP (Geels and Schot, 2007). This challenges the usefulness of the MLP in investigating transitions to futures and further reinforces the argument in section 6.6. Rather, this study used concepts from the MLP and architectural innovation.

6.8 CRITICAL REFLECTIONS ON INNOVATION IN TRANSITIONS

Innovations come to the fore in transition literature. This section reflects on identified technological and business model innovations in Chapter 4 and 5 and discusses them in light of literature to argue that (1) there are multiple innovations in transitions to future (2) historical innovations are modular and unable to change the whole electricity system and (3) interviewees do not realise that innovations in futures are mostly part of architectural innovation. This reflection also reveals the contribution of this study to transition and innovation studies as well as the industry.

Firstly, Chapter 4 and Chapter 5 show that there are a wide range of innovations which are currently developing or are likely to be developed in the future. For example, in future 4, many technological innovations and business model innovations which are consumer-focussed were described, such as EVs, EVs time-of-use tariff, energy service companies and their bundles. These findings reveal that there are likely to be multiple innovations in the future which is in line with recent transition studies (Geels, 2018b; McMeekin *et al.*, 2019). By recognising that innovations are multiple, the sector might be more open to a different way of understanding, conceptualising and evaluating the role of each innovation in transitions as discussed below.

Secondly, Chapter 4 and 5 also show that there are a significant number of existing technologies (historical innovations) such as PVs, energy efficiency and EVs which have played a key role in the development of GB's electricity sector. The development of PVs has brought about a significant increase in the number of actors involved in electricity generation which challenges the management of network. Energy efficient innovations reduced demand in the consumption sub-system. The existence of EVs may increase demand at a specific time of a day and consequently pose a threat to the distribution grid. This finding is similar to a number of literature supporting the development of a single technological innovation as sufficient for transitions of the sector (Geels, 2002; 2005a). However, these innovations are component/modular innovations in the sense that they only change the core concept and working of a single sub-system. By themselves, they are unable to bring about changes in the whole system of generation, distribution and consumption. This finding accord with recent transition literature which conceptualises transitions as changes in the whole system level (Geels, 2018b; McMeekin *et al.*, 2019).

Thirdly, interviewees do not realise that a large number of technological innovations identified in Chapter 4 and 5 and summarised in section 4.2.4 such as the further uptake of EVs and smart grids could create system level change, i.e. are part of architectural innovation. The further uptake of EVs is architectural because it can enable demand side flexibility and consequently, changes the relationship between consumers and the electricity network. Consumers participating in demand side flexibility may be able to not only help DNOs reduce network constraints but also help system operators balance the grid. Similarly, smart grids are part of architectural innovation which support the two way flows of electricity change the relationship between generation, network and consumption subsystems because it (1) helps DNOs and system operators to deploy flexibility from consumers to overcome network issues, (2) supports the development of low carbon generation and (3) facilitates the uptake of EVs.

Some business model innovations at the firm level identified in Chapter 4 and 5 are also able to impact transitions at the system level. For example, with the case of energy service companies in Future 4 which manage home appliances on consumers' behalf, the relationship between consumers, suppliers and network may change. The relationship with energy suppliers will change because consumers may receive bills directly from energy service companies, rather than their energy suppliers. The relationship with the network changes because consumers can participate in demand side flexibility, although indirectly by authorising energy service companies to manage their demand. As the penetration of energy service companies involve changes in the linkages between consumers with suppliers and the network, it is classified as an architectural innovation.

As these technological and business model innovations can potentially involve changes in the linkages between traditional sub-systems (components) within GB's electricity system and consequently change GB's electricity system architecture, they are part of architectural innovation. Table 6.1 summaries some architectural innovation identified in Chapter 4 and Chapter 5 and their impacts on system architecture.

This finding about architectural innovation reveals that the GB's electricity sector will potentially experience a period of restructuring system architecture in which the linkages between three conventional sub-systems generation, distribution and consumption are fundamentally altered. This finding accords with the anticipation of recent empirical research on architectural reshaping of GB's electricity sector from 2015 (McMeekin *et al.*, 2019). However, this McMeekin et al (2019) research is based on the historic analysis of GB's electricity sector from 1990 to 2015 to anticipate futures whereas this study investigates architectural innovation in the future.

Despite the importance of architectural innovation, there is little comparative attention paid to architectural innovation, especially in GB's electricity sector context and futures. Hence, this finding about architectural innovation not only contributes to transitions research but also suggest that further research on architectural innovation in transitions is required.

Key issues within an organisation with regards to architectural innovation are recognising architectural innovation and understanding how to integrate architectural innovation as it involves changing the linkages between the organisation and wider system (Henderson and Clark, 1990). Indeed, the majority of interviewees do not recognise the changes in system architecture arising from an innovation. By identifying architectural innovation and suggesting how system linkages may change and hence, engender transitions, this study shifts debate and discussion to whole system transition. The following section discusses this whole system change.

Table 6.1: Architectural innovation and their impacts on linkages of traditional sub-systems

Architectural innovation	Changes in linkages of sub-systems
Further uptake of EVs	Distribution, Consumption
Smart grids	Generation, Distribution, Consumption
Energy service companies	Distribution, Consumption
Consortia	Distribution, Consumption
Transmission grid-battery storage connecting with EVs charging model	Generation, Distribution, Consumption
Technology platform for flexibility (new entrants)	Generation, Distribution, Consumption
Flexibility platforms (DNOs)	Generation, Distribution, Consumption
Flexibility time-of-use tariff	Generation, Distribution, Consumption
Demand side flexibility	Generation, Distribution, Consumption

6.9 CRITICAL REFLECTIONS ON WHOLE SYSTEM ANALYSIS

The findings and the discussion about technological determinants of the sector in section 6.3.1 show that a majority of interviewees considered transitions as predominantly technological. In contrast, a small number of interviewees argued that transition should be at the *system* level, rather than focus on technological sub-systems. Although only a small number of interviewees acknowledged the vision of system level changes, Chapter 5 shows that the potential outcomes (whether or not preferred by the existing energy policy) of transition in Future 1, 2, 4 and 5 are, in fact, at systemic level. Future 1 sees the blending of different business models in one technology platform at real time. As a consequence, the boundary of conventional generation, network and consumption is blurred and replaced by one boundary of a market for different users and providers of flexibility. The transition to Future 1 is at systemic level in the sense that conventional sub-systems of the sector cease to exist and the boundary of the system is changed. Similarly, the boundary and purpose of the system changes towards the operation of the network in Future 2, and towards the consumers in Future 4. In Future 5, although the boundary of generation, network and consumption are realised, these sub-systems are overlapped, especially in the prosumer element. Prosumers are able to generate, consume their own generated electricity and only use electricity grids as electricity supply back-ups, i.e. they disrupt the arrangement of current transmission, distribution grids. Such overlapping of the boundary is at systemic level because it changes these sub-system separation arrangements and relationships established by the current regulatory framework. This finding not only shows the importance of recognising the systemic nature and level of transition but also identifies the outcome of transitions at systemic level, i.e. the changes, the overlap or blending in system boundaries.

Although recent industry publications call for a whole system analysis, they usually analyse a whole technological system, rather than a socio-technological system. The latter explicitly includes the socio aspect (e.g. actors and their interactions with other system components) as important to bring about transitions. It suggests that the critical review of the conceptual framing of GB's electricity system and the nature of the *whole system* is urgently needed.

In transitions research, recent publications recognise the needs to consider socio-technical transitions as a system question (Mitchell, 2008; Geels *et al.*, 2019; McMeekin *et al.*, 2019). However, these publications do not explore what the outcomes at the systemic level look like in the future. This finding therefore contributes to the literature on transitions research.

6.10 DISCOURSES IN TRANSITIONS

This section provides critical reflections on the usefulness of (1) discourse coalition approach, (2) the dominant energy discourses and also briefly discusses (3) Dryzek's (1997) discourse analysis framework in transitions.

6.10.1 Critical reflections on discourse coalitions

Actors are grouped into discourse coalitions, but it is noticeable in Chapter 4 (section 4.7) that interviewees do not neatly fit in one single discourse coalition. They appear in and/or support two or more futures regardless of their positions in GB's electricity sector. However, it does not mean that discourse coalition approach is invalid. Rather, this finding suggests that actors in the sector hold a plurality of views on energy futures and transitions which may even be contradictory and associated with multiple futures. This finding is in line with the conceptualisation of discourse coalitions which consists of actors who from the various backgrounds and do not necessarily hold the same views or interests (Hajer, 1993; 1995; Kern, 2012). Ultimately, futures articulating from these discourse coalitions are messy which reinforces the argument in section 6.2. Therefore, discourse coalition is a useful conceptual and methodological approach and tool to bring new insights to transitions research and the industry.

Moreover, Chapter 5 shows that each future, beside the dominant discourses used to articulate futures, contains the discourses of technology-focus and energy flexibility (see section 4.7.2). This reveals the complexity of the real-world where transitions are socially constructed and opens an opportunity for further analysis on the interaction of actors and their visions of energy futures.

6.10.2 Critical reflections on existing energy discourses

The boundaries of the discourses identified in Chapter 4 and 5 are unclear and far from obvious. This section draws out the overlaps of these discourse coalitions and further shows that futures are open-ended.

Economic rationalism is represented by individuals or organisation with *"individual interest"* and there is "*no citizen*" acting towards public interests (Dryzek, 1997, p.117). However, some "*public interests*" are evidenced in Future 1, e.g. in the case of the availability of data for every half hour of day, both consumers and energy suppliers are expected to have benefits. Here, economic rationalism fulfils one of the characteristics of ecological modernisation.

Administrative rationalism emphasises "*the role of experts rather than citizen or producer/ consumers in social problem solving, and which stresses social relationships of hierarchy rather than equality or competition*" (Dryzek, 1997, p.63). The market is underestimated in administrative rationalism. However, in Future 2, it is evident that market is salient to some extent. Evidence needed for state administration in this future not only comes from research of experts but also from market demonstration. Market demonstration is even more important than research because it can evaluate the effectiveness of research according to interviewees. Moreover, one of the options for DNOs in Future 2 to resolve network constraints is to bring demand side flexibility to market (e.g. by contracting with market actors to procure demand side flexibility). Here, the boundary of administrative rationalism is extended and the future moves closer to economic rationalism.

Furthermore, in administrative rationalism, consumers are not emphasised. However, the finding in Future 2 shows that some interviewees expect that consumers (including both domestic and I&C consumers) will have control over technologies to participate in demand side flexibility. If this transpires, Future 2 will move closer to consumer sovereignty and energy democracy discourses.

Ecological modernisation advocates that the ultimate role of government is to restructure policy along a decarbonisation agenda (Dryzek, 1997). However, some of government decisions are highlighted to be based on evidence from research by interviewees in Future 3. For example, the government support towards CCS is recommended by the Committee on Climate Change carbon budget (2015b). Here, ecological modernisation and administrative rationalism are overlapped to some extent.

With the identified changes and overlaps in these discourses, all of the futures are contingent and being more open-ended. This insight again reinforces the discussion in section 6.2 suggesting that the futures of the sector are going to experience a period of changes which, because of these overlaps in discourses, will be difficult to steer, manage and control as expected by the sector and actors involved.

6.10.3 Reflections on Dryzek's discourse analysis framework

This study suggests Dryzek's framework (developed in section 2.6.1) is a useful framework to analyse energy discourses and energy discourse coalitions. The two elements of the framework (basic entities and assumptions about natural relationships) are able to help elaborate futures at the whole system level. The last element of the framework (key metaphors and other rhetorical devices) emphasises the role of language in transitions – including the extent to which language is subject to critical review and contestation. However, the third element (agents and their motives) offers less explanatory insight because it is at odds with the conceptualisation of power in transitions following constructionism where power is not only held by actors (Ahlborg, 2017; Cashmore, 2018). This suggests further development of the Dryzek's framework and more empirical research might be needed to evaluate this framework. The following section offers some critical reflections on power.

6.11 CRITICAL REFLECTIONS ON POWER IN TRANSITIONS

This section provides a critical reflection on how the notion of power can be usefully understood and how power engenders transition. The findings show that transitions emerge from the *interaction and relationships* of power among human and non-human elements while transitions literature considers power as being possessed by human actors. This suggests the notion of power needs to be reconceptualised and understood in transitions literature.

The findings in Chapter 5 (section 5.2.3, 5.3.3, 5.4.3, 5.5.3, 5.6.3) show that power of actors is exercised in interaction with non-human elements. For example, in Future 3, a government may engage with the industry (i.e. market actors) to pursue its interest in decarbonisation and economic growth since market actors recognise decarbonisation will lead to increasing profits. However, market actors' interest in profit may not be achieved if consumers' interest is not based on economic rational behaviour. Such pursuit of profit may be restricted by non-human external factors such as infrastructure, e.g. whether network and charging infrastructure supports EVs development.

Here, transitions emerge from not only the interactions and power transfer between actors but also from power of non-human elements (i.e. structural power). The finding in Chapter 4 (section 4.4.1) reveals that the most powerful non-human element affecting transitions is the "*fundamental physics*" of the system (i.e. the requirement to balance the network at all times). This element is classified as a system stability which needs to be maintained during transition.

There are also several other "*structural powers*" identified in the findings in Chapter 4. These structural powers are conceptualised as "*barriers to overcome*" by interviewees, including technology, finance, market, information and regulation. Among them, the power of regulation emerged as the most significant. The majority of interviewees across different futures highlighted the need for an amendment to the regulatory framework for the electricity market to, among other things, enable new entrants to access data, enter new markets and capture value (see section 4.4.2.3.2, 4.4.2.5, 4.4.2.6). A further need to change the whole regulatory structure was suggested by a minority of interviewees.

This view challenges the utility of the predominant conceptualisation of power in transitions literature (reviewed in section 2.4.3) where the focus of actors' capacity has been brought to the fore (Avelino and Rotmans, 2009) and power to orchestrate changes is held by individuals and society (c.f. Cashmore, 2018). Power does not lie solely in actors but is also embedded in actors' relations with socio-technical structures. As such, power should be understood as a productive force (Cashmore, 2018). This conceptualisation takes into account the view of Foucault towards power in which powerful individuals do not possess power (Cashmore, 2018). Rather, power is expressed in the societal interactions between human, technologies and nature (Ahlborg, 2017).

By conceptualising power as a productive force, the outcomes of transitions might be "*contradictory and ambiguous*", i.e. messy (Ahlborg, 2017, p.6). Such messy outcome is in line with social constructionism and the discussion in section 6.2. This suggests transitions cannot be simply realised by power exchange between actors but by a range of power interactions among both actors and structure.

6.12 REALISING ENERGY FLEXIBILITY

As the term "*energy flexibility"* appears in the commentaries of all interviewees, this penultimate section briefly discusses these commentaries to understand how energy flexibility can be realised in the future. Energy flexibility is assumed to be a technological question by the majority of interviewees. However, these technologies potentially engender changes in the architecture of the system which is at odds with the perspectives of BEIS and Ofgem. This suggests a more sophisticated transition conceptualisation, implementation and management strategy is needed to realise energy flexibility.

In terms of new sources of energy flexibility, including demand side flexibility, storage and interconnection, the findings reveal that the focus has been on demand side flexibility, while storage and interconnection receive comparatively little attention from interviewees. Even so, energy flexibility has been conceptualised very differently by interviewees. Energy flexibility is that which "*holds the system togethe*r" or which drives "*market volatility for technologies and market entrants*" or about "*understanding network capacity and energy throughput rather than maximum demand*" or to "*manage your demand in a way which you can align it better with renewable generation*" or "*a consumer flexibility to replace inflexible generation technology*". Here, energy flexibility can be considered as a system aspect, a market aspect, a demand aspect or a grid aspect, depending on the perspective of the interviewees talking about energy flexibility.

Despite different ways of conceptualisation of energy flexibility, the finding shows that the majority of interviewees do not critically review their own or others' conceptualisations but consider futures' energy flexibility in general terms and demand side flexibility in particular as a technological question. In other words, energy flexibility can, for interviewees, be easily achieved by adding technologies or knowledge into the system. For example, a technology platform or a flexibility time of use tariff in Future 1, smart grids in Future 2, or consumer-centric innovations in Future 4.

This finding resonates with BEIS and Ofgem perspectives in energy flexibility who assume that a smart and more flexible energy system (2017, p.4; 2018, p.3) can be achieved by,

> *"- removing barriers to smart technologies, including storage;*
> *- enabling smart homes and businesses; and*
> *- making markets work for flexibility".*

Transition is assumed to occur by (1) removing barriers, (2) incentivising consumers with financial rewards and (3) ensuring value of flexibility by transparent price signals. In other words, BEIS and Ofgem assume that consumers and the industry act rationally following economic incentives and transitions can be easily achieved by removing barriers, thus, unaware of and/or undermining the importance of systemic changes. As discussed in section 6.5, this view is embedded in realism ontology which may prevent energy flexibility from being realised in futures.

In contrast, as argued in the finding relating to "the metaphor of energy flexibility" in Chapter 5, some interviewees recognised that these technologies potentially involve changes in the boundaries between conventional sub-systems. The technology platform in Future 1 may allow different market actors from traditional market and sub-systems to participate and consequently, alter the traditional market structure and system architecture. Similarly, smart grids in Future 2 facilitate network companies to understand and procure demand side flexibility from the market, which involves market entrance of new actors and as a consequence, alter system architecture. These technologies can be considered as or constitute architectural innovation which engender changes in the architecture of the whole system. Ultimately, the finding suggests that the transitions to energy flexibility can be achieved by architectural innovation, rather than modular innovation, and is a system-level question, rather than a technology question.

6.13 SUMMARY

In summary, this chapter reveals the uncertainty and messiness of futures of the sector which is at odds with *tidy* futures envisaged in transitions research and industry literature. This insight sheds light on a different understanding of transition management which contains a more nuanced and complex view. Rather than thinking of a pre-defined outcome (i.e. a transition goal) by following a transition pathway, transition of the sector should be understood as being socially constructed and emerge as a result of the interactions of different actor groups and other system components.

Such interactions determine the feasibility of identified futures of the sector. Future 3 is most likely compared to other futures because it is supported by the most recent energy policy and able to accommodate the interests of the largest number of actor groups.

This chapter also discussed the determinants of identified futures. Via similar determinants including technologies, non-technological determinants (market, culture, consumers) and regulation, the predominant assumption of the industry towards transitions is revealed. Transition is assumed to proceed by adding technologies and/or knowledge to the existing system and by removing barriers.

The discussion about the determinants of the five identified futures also leads to further insights on the inconsistencies in ontology (i.e. the way industrial actors realise transitions) and the approaches taken in academic literature. The sector view is embedded in realism where economic rational choice is advocated to bring about a linear transition. This mostly involves the process of adding technologies and/or knowledge to the system. It also advocates that a pre-defined goal of transitions is essential in order to plan actions. However, established transition approaches detailed in academic literature share the view that transitions of the GB's electricity sector advocate a constructionist view of transitions and their management. Accordingly, transitions are complex and uncertain and cannot be simply planned. Transitions need to occur at the system level with architectural innovation playing a key role. This view suggests a shift in the established knowledge of the sector towards a more sophisticated understanding of transitions and human behaviour, the need for systemic management of the energy system and a rethinking of future making practices.

Future making practice in industry literature is dominated with modelling exercises which, while important, remain highly technical and leave little room for uncertainty. Moreover, transitions frameworks including the MLP also *clean up* the actual processes of transitions in order to make transitions governable and as a consequence, are not able to represent or capture the complexity of transitions. This finding calls into question the usefulness of current future making practices based on modelling tasks and fixed transitions frameworks.

This chapter also reflected on some key concepts of transitions research such as the MLP and architectural innovation in order to understand the needs for the whole system analysis of transitions. Currently, transition is mainly conceptualised as a technological change where symbiotic innovations are likely to supplement existing incumbent technologies and bring about system reconfiguration. These added innovations in technologies and business models are part of architectural innovation which involve more fundamental changes in the relationships between the sub-systems. However, interviewees do not realise these changes. Therefore, this study provides a critical shift in our understanding of transitions. Transition needs to be understood at system level, rather than at technological level. This study contributes to the literatures in transitions research by identifying not only the needs of system transition involving the interaction of system components (including actors) but also the outcome of transition comprising of the overlaps of different sub-systems.

This chapter has also discussed discourse theory in transitions research in light of industry literature to understand the usefulness of the discourse coalition approach in identifying different perspectives of actors within a future. Interviewees do not neatly fit in one single discourse coalition which suggests that actors in the sector hold a plurality of views and interests. As such, the futures articulated by these actors are messy which reinforces the discussion about actors' interactions. Indeed, discourse coalition approach offer significant scope for capturing the messiness of futures.

Beside the usefulness of discourse theory in transition, reflecting on the notion of power deepens our understanding of power in the industry and transitions research. The majority of interviewees assumes power as being possessed or held by human actors. Similarly, in the literature, transition is predominantly understood as emerging through the *interaction* of actors. However, this understanding undermines the power of structure which is evidenced in the findings as an important type of power to engender transitions. Hence, instead of being held by individuals, power should be re-conceptualised as a *productive force* which comprises a range of power interactions among human and non-human elements. This conceptualisation broadens the understandings of whole system transitions and leaves rooms for, and indeed helps to explain, messy futures.

This chapter concludes with the discussion about realising energy flexibility in futures. Energy flexibility involves changes in the architecture of the whole system. However, the dominant perspective and metaphor of government and the regulator in planning for a smart and more flexible future is based in realist ontology, which undermines the importance of systemic changes. This perspective challenges how energy flexibility is conceptualised and may be realised. Transition to energy flexibility is not just about technological additions but requires a systemic understanding of transitions.

CHAPTER 7 CONCLUSIONS AND RECOMMENDATIONS

7.1 INTRODUCTION

This chapter summarises the key findings, conclusions and corresponding recommendations of this study as follows. It begins with a review of the research aim and objectives. This chapter then reflects on the methods selected and adopted in this study. After that, both the key findings and the conclusions of the study are set out. Limitations of the study are then considered. Finally, implications for the industry and recommendations for further research are detailed.

7.2 REVIEWING RESEARCH AIM AND OBJECTIVES

GB's electricity sector is transitioning to low carbon futures in response to climate change and associated legally binding targets. Most of the UK research on transitions to futures of the sector focuses on technologies, while some other research has started to steer the focus onto actors and their power. However, such research fails to capture (1) the mess of futures emerging from the interactions of actors and (2) the whole system spanning generation, distribution and consumption sub-system of GB's electricity sector. A third gap in knowledge identified in Chapter 2 centres on the lack of attention on how transitions to new sources of energy flexibility may be achieved. With these in mind, the following research aim was identified:

> *To critically investigate whole system transitions to low carbon futures and new sources of energy flexibility in GB's electricity sector.*

In order to meet this aim, three objectives were developed.

Research objective 1:

> *To identify dominant energy discourse coalitions within GB's electricity sector*.

The beginning of Chapter 4 presented a thematic coding analysis of data to reveal diverse assumptions of interviewees about the transitions of the sector. The last section of Chapter 4 (4.6) drew on these assumptions and main characteristics of contemporary energy discourses in literature (presented in Chapter 2 – section 2.6.2) to group actors into discourse coalitions. Actors in a discourse coalition share a set of assumptions. Seven dominant energy discourse coalitions were identified: (1) economic rationalism, (2) administrative rationalism, (3) ecological modernisation, (4) consumerism, (5) energy democracy, (6) technology focus and (7) energy flexibility.

Research objective 2:

To identify futures of GB's electricity sector, focussing on the whole system analysis.

These discourse coalitions act as a bridge from thematic coding analysis to discourse analysis in Chapter 5. These discourse coalitions form the basis of futures of the sector in this study and thus help to meet this second research objective.

This objective of identifying futures was then met by discourse analysis following Dryzek's (1997) analytical framework presented in Chapter 2, section 2.6.1 (Table 2.4) which includes four elements: (1) System components; (2) System relationships; (3) Power; and (4) Metaphors of energy flexibility. Five futures were articulated: (1) a 'Market-based' future, (2) a 'Network-focussed' future, (3) a 'Policy-driven' future, (4) a 'Consumer-centric' future; and (5) a 'Prosumer-led' future.

The focus on whole system analysis was achieved by (1) mapping the imagined future of each discourse coalition, (2) identifying and investigating architectural innovation and (3) exploring the notion of power in transitions. Firstly, each future was mapped in a systems map to represent the researchers' interpretation of each future. Although all interviewees may not agree with or endorse these system maps, they clearly show whether and how the conventional sub-systems: generation, distribution and consumption feature in any futures.

Secondly, Chapter 2 (section 2.4.2) explored how architectural innovation may engender changes in system architectures (i.e. changes in the relationships between subsystems), and consequently, give rise to transitions in the whole sector. The findings in Chapter 4 and Chapter 5 and the discussion in Chapter 6 (section 6.8 and 6.9) identified some innovations (e.g. energy service companies, smart grids, platforms for flexibility) and showed that these innovations not only influence a part of the system where they are situated but also potentially transform the traditional linkages between various sub-systems and thus, bring about or themselves constitute architectural innovation.

Thirdly, Chapter 2 (section 2.4.3) highlighted the need to conceptualise power not as something held by actors but as the power of actors exercised within contexts (structures) in the whole system analysis. Chapter 5 (section 5.2.3, 5.3.3, 5.4.3 and 5.5.3) and Chapter 6 (section 6.11) explored how power is conceptualised and identified in energy futures, not only in relation to human actors but also in relation to technology and regulation (structural power). This whole system analysis to identify futures informed and helped to meet the third research objective.

Research objective 3:

> *To identify how transitions to new sources of energy flexibility may be achieved in each future*.

The findings presented in Chapter 5 (sections 5.2.4, 5.3.4, 5.4.4 and 5.5.4) showed that the majority of interviewees considered energy flexibility as a technology added to the system, for example a technology platform or a flexibility time of use tariff in Future 1, smart grids in Future 2, or consumer-centric innovations in Future 4. However, the discussion presented in Chapter 6 (sections 6.8 and 6.12) showed that the sector and policy makers do not realise that these technologies are architectural innovation which can create system level changes. As a consequence, these suggest a system level-response is required to achieve transitions to new sources of energy flexibility, but such response has yet to materialise.

All three research objectives have been met and this study has completed an exploratory research. The following section sets out some critical reflections on the method chosen and applied in this study to achieve the research aim and objectives.

7.3 METHODOLOGICAL REFLECTIONS

This section provides a critical reflection on the research method in terms of (1) data collection and analysis and (2) research quality.

7.3.1 Data collection and analysis

In order to meet the research aim and objectives, qualitative data were collected from various sources including most notably via semi structured interviews with senior figures in GB's electricity sector. Such insights were used to identify and explore GB's electricity sector futures and associated transitions. It should be noted that it was far from easy to access these senior figures, even with the assistance of the researcher's industrial supervisor. Indeed, there is a paucity of research founded on such insights and this study offers a unique and privileged view into how transitions in GB's electricity sector are envisaged by sector leaders.

The study is founded in the constructionist perspective. Data were analysed using a thematic coding analysis and discourse analysis in Chapters 4 and 5 respectively. "*Thick descriptions*" (Geertz, 1973) were developed from the qualitative data collected. Such an approach to data collection and analysis provides a powerful way of exploring transitions of GB's electricity sector and how they actually unfold rather than focussing on historical transitions via documentary analysis as adopted by much current research (c.f. Geels *et al.*, 2016; McMeekin *et al.*, 2019).

This study explores how transitions emerge from the interactions of actors and other system components. As such, focus groups or workshops are effective and efficient way to gather a large amount of data and attain knowledge about power relationships through interactive discussion (Robson and McCartan, 2016). However, such data collection approaches were not used as it would have been very difficult to organise focus groups or workshops with senior figures who are busy and difficult to access. Moreover, due to Covid-19 and its associated lock-down and online working, it was unfeasible to do so.

7.3.2 Research quality

As identified in section 3.2.9, a flexible research design produces credible and transferable results and conclusions.

Credibility is achieved in this study from "*prolonged involvement*"" and a transparent audit trail over the 4 years of this study. During this period, the researcher was thoroughly immersed in the GB's electricity sector and attended industry conferences and workshops and conducted interviews. The research design set out in section 3.3 forms an audit trail which provides the readers with a step-by-step overview of the research process and contains the following documentation of:

- the researcher's prior understanding and perspective which influences the expectations of the study and consequently the research aim and objectives.
- sampling strategy.
- research data collection methods and context which impact the choice of data collection strategy.
- data via transcripts and records.
- methods of analysis.
- the criteria which this study needs to satisfy.

This study satisfies transferability in terms of "*analytical generalisation*" as it adopted the concepts from the MLP, architectural innovation, power and discourses in transition with an analytical framework of discourse analysis and discourse coalitions which may spread outside the boundary of GB's electricity sector.

Conclusions drawn from this study are provided in the following section.

7.4 KEY FINDINGS AND CONCLUSIONS OF THE STUDY

This section draws out three main conclusions of the study, based on the findings and discussions presented in Chapters 4 to 6, namely:

- Futures are messy which highlights the multiplicity, contingency and open-endedness of energy transitions.
- Energy transitions can be usefully understood as socially constructed and conceptualised as whole system analysis.
- The dominant engineering perspective of GB's electricity sector, the continuing belief in rational choice behaviour and the preponderance of short-term view of futures are highlighted as key issues in managing transitions.

7.4.1 Open-endedness, multiplicity and contingency of energy transitions to futures

This study identified five futures articulated by actor coalitions who ascribed to five dominant energy discourses. However, this study shows that actors cannot be easily marshalled into actor coalitions associated with one future because they hold a plurality of views about futures, which are sometimes contradictory and unclear. Hence, futures are messy and uncertain. Such messiness and uncertainty of futures in the findings underpin the complexity of the actual process of transitions. Indeed, this study suggests the multiplicity, contingency and open-endedness of energy transitions.

- Multiplicity: This study shows that there are multiple innovations in the future and it is uncertain which one(s) will dominate. There are multiple transition pathways to futures, shaped by multiple discourses. In each future, multiple human and non-human elements interact and give rise to transitions.
- Contingency: Futures are contingent upon both human and non-human elements such as actors, regulation, technologies, infrastructures and business models.
- Open-endedness: This study shows that the outcome of transitions is uncertain and open-ended. Transition objectives may be set in advance, but are likely to change. In turn, the outcomes of transitions may be surprising and unexpected.

This study shows that the futures are much messier and more complex than currently represented in much academic and industry literature. Futures elaborated in these literatures are neat and clearly delineated. Transition frameworks such as the MLP to govern transitions to these futures provide a simplified view of transitions in order to visualise key socio-technical elements and consequently, render transitions manageable and actionable. As such, these frameworks far from fully account for the messiness and complexity of energy transitions and futures.

7.4.2 Whole system analysis of transitions

This study shows that energy transitions should be understood as being socially constructed from the power of relations/ interactions between actors and other system components and require architectural innovation.

- Power: This study shows that power in energy transitions should be understood as a productive force following Cashmore (2018), rather than the capacity of actors to take action (i.e. agency) as conceptualised in much recent transitions research (c.f. Avelino and Rotmans, 2009). Power, hence, is not possessed by actors, but the outcomes of social interaction of actors embedded in societal structures.
- Architectural innovation: This study recognises the key role of architectural innovation in energy transitions which is paid comparatively little attention in transitions research. This study shows that these innovations involve changes in the architecture of the whole system and as a consequence, engender transitions.

With insights from the notion of power and architectural innovation, this study suggests that energy transitions will occur at the system level. Transitions research, hence, should not only focus on technologically focussed modular innovations but also whole system analysis. It means that the whole system should also be considered as the unit of analysis. This allows a fuller account of the interactions of system components and their linkages. However, the industry does not embrace such a perspective or indeed, system change, instead preferring to envisage and manage a technological change. Having highlighted this key issue of GB's electricity sector, the following section looks at key issues of transition management in the sector.

7.4.3 The key issues of transition management in GB's electricity sector

This study investigated what is actually, and expected to be, happening in transitions of GB's electricity sector and found that key actors in the sector follow a realist ontology. This established ontology creates difficulty for the sector in general and policy makers in particular to manage transitions. Key issues are related to the dominant engineering perspective of actors including policy makers, the continuing belief in rational choice behaviour and the preponderance of short-term view of futures.

The first key issue of transition management is the engineering perspective of the sector towards transitions. The sector does not see that transition is a system question. Rather, transition is assumed as linear processes of adding technologies and/or knowledge to the system, i.e. a technology question. This assumption, however, simplifies the actual process of energy transitions. This study shows that changes in a system component can give rise to changes at a system level which the sector may not expect. Consequently, the sector, while not foreseeing how a technology might reshape other system components and the system architecture, might face an unexpected outcome and ultimately, transition to a different future than envisaged.

The engineering perspective widely held in the sector is also revealed in the neat and clearly delineated futures articulated by the industry such as National Grid - Future Energy Scenarios (2019b), Energy UK - The Future of Energy (2019), Energy Networks Association - Networks Future Worlds (2018), Shell - Sky Scenario (2018) and Committee on Climate Change - Power sector scenarios for the fifth carbon budget (2015a). Transitions to the futures are assumed to be manageable and controllable by setting a predefined objective and proceed linearly towards such objective. However, this study shows that transition objectives can change over time and transitions involve unintended outcomes. This insight questions the reliance and utility of neat and clearly delineated futures in literature.

Policy makers also accept and embrace the engineering perspective as illustrated in key policy documents from the government and the regulator (BEIS and Ofgem, 2017; 2018). Policy makers assume that transitions can be achieved by removing barriers (mostly non-technological barriers). As such, transitions are deemed to be easily controlled and delivered which do not fully account for the actual process of energy transitions. Transitions cannot be easily achieved by removing barriers but involve changes at a system level.

The second key transitions management issue revealed by this study is the predominance of the rational choice perspective in the sector. The sector assumes that humans act rationally in response to economic incentives. Choices associated with innovations and how they might work in the future are based on this viewpoint. Decisions are often made using cost-benefit analysis of technologies. A technological choice is then articulated, rather than a system choice. However, this technical practice overlooks the real relationship between technologies and other system components as well as the whole system. Moreover, both academic literature and this study show that consumers do not follow economic benefits. There is, hence, an inconsistency between the framing and expectations of consumers in the sector and how consumers actually behave. As consumers can potentially form a key aspect of transitions, this inconsistency creates difficulty for developing appropriate transition management strategies.

Thirdly, this study shows that actors mostly have unclear visions about the development of the sector. Indeed, these visions seem to be short-term. This suggests the sector is expecting to see a small amount of changes and reveals the inertia of the sector in dealing with innovation. The sector expects transitions to be '*in control*'. Thus, such short-term vision does not aid planning purposes.

Although the research aim and objectives are all met, which can subsequently provide a practical implication for the industry (to be described in section 7.6), this study is not without limitation. The following section discusses these limitations.

7.5 LIMITATIONS OF THE STUDY

There are some limitations of the study in terms of methods and the scope of the study.

Firstly, this study's semi-structured interview approach to data collection might be a limitation as interviewees may provide information on the basis of what he or she thinks the researcher would like to hear (Silverman and Marvasti, 2008). As such, collected data might be filled with platitudes which are not be useful in this study. To counter this, observation of industry-based conferences was adopted which was helpful in aiding the researcher's sense making.

Secondly, another limitation lies in the possibility of researcher bias while approaching thematic coding analysis. The interpretation of codes and themes may reflect the researcher's interest which would be a threat to credibility. However, as mentioned in section 3.2.3, this should be considered as the subjectivity of the researcher, rather than bias – deliberate attempts by the researcher to condition the results of the research. In this study, subjectivity is explicitly addressed because the researcher was reflexive and followed the progressive funnel approach where the researcher gradually and iteratively refined the literature review, data collection and data analysis. The researcher also provided transparent audit trails of documents and analysis.

Thirdly, this study is founded on constructionism to investigate transitions to futures of GB's electricity sector. As such, this study does not offer a clean description of what these futures look like and therefore, does not articulate clear actionable solutions for transitions management. In contrast, this study frames the vision of different actor constituencies and acknowledges the contradictory and messy outcomes of transitions. Hence, the contribution of this study is not theory testing or theory building of socio-technical transitions. This study rather develops an interpretation of future expectations of different actor constituencies to aid those interested in open-ended research investigating how transitions actually unfold.

Fourthly, this study only investigated electricity sector's transitions in a GB context. The findings hence might not be representative to apply generally (Bryman and Bell, 2011). It means that the findings might not represent other sectors in Britain and other electricity sectors in other countries. However, "*statistic generalisation*" is not the goal of a qualitative case study research. Rather, this study developed a deep understanding of expected transitions in GB's electricity sector and confirmed the uniqueness of this case study.

Finally, data were not collected from actor constituencies such as consumers, prosumers, community energy groups and local authorities. These actor constituencies may become increasing important in GB's electricity sector (highlighted in Future 5). However, as mentioned above, generalisation or representation is not a goal of this study.

7.6 IMPLICATIONS FOR THE INDUSTRY AND POLICY

The implications of this study hinge on the issue that the system architecture of Future 3 (Policy-driven future), which is preferred by the current existing energy policy, remains largely intact (see section 6.4). This suggests both the sector and policy makers do not foresee the changes at the system level, which is incompatible with the actual energy transition processes. Therefore, it will be difficult for the sector and policy makers to develop appropriate transition management strategies and will hinder this "*policy-driven*" transition of the sector. This incompatibility underlines a need for a shift to a more sophisticated understanding of energy transitions within the industry and the government. Key points are:

- Recognise that incentivising consumers through price mechanism might not work.
- Understand that changes in one part of the system can engender changes in the whole system.
- Greater attention is needed on architectural innovation which involves changes in system architecture.
- Embrace the multiplicity of transitions which involve multiple pathways, multiple actors and innovations.
- Articulate system choices, rather than just technology choices of transitions.
- Embrace the notion that transition goals or objectives can change overtime although the overarching aim of transition is decarbonisation.

This study also suggests that future making practices in the electricity sector which are dominated by quantitative modelling analyses should be challenged as a basis for management and decision making. Modelling might be too technical and limited to fully capture the uncertainty of futures and the system change that a transition may involve; thus, need to be complemented by whole system analysis.

More generally, the sector and policy makers can draw on the conclusions and the insights from this study to reflect on their own sense of transitions and act in their own context to review and re-make futures, plan and manage transitions. Without the greater understanding of energy transitions and the change in energy future making practices suggested in this study, the sector will be unable to deliver the required energy flexibility in the future and ultimately unable to transition to low carbon futures. This study hence contributes to one of the ways in which the sector and policy makers can position themselves to effectively transition and achieve the Net Zero target.

7.7 RECOMMENDATIONS FOR FURTHER RESEARCH

As this study is exploratory, it implies that new insights on low carbon transitions and energy futures are needed. Recommendations for methods used in subsequent research are as follows:

- Constructionism research ontology: This ontology can be further adopted in exploratory research in transitions. Transition is future-oriented and futures are produced through the interactions of actors in particular contexts. This ontology opens opportunities for understanding how different elements interact and give rise to transitions.
- Abductive logic of enquiry: this logic of enquiry can be useful because it allows the researcher to gain insights into a phenomenon, rather than to test theory or build theory. The researcher is able to use concepts and ideas from some theoretical frameworks to inform the research questions and then amend research questions when the research proceeds.
- A holistic case study: This research strategy is useful as it steers the focus of the research onto a whole system analysis. Here, the whole system is the unit of analysis.
- Semi-structured interview with observation: Semi-structured interviews with senior figures and observation in industry-based conferences are useful in gaining insights and prevailing discussions of actors in the sector, and indeed, to capture their contemporary discourses. However, gaining access to these interviewees and conferences should not be under-estimated.
- Purposive and snowball sampling: Adopting purposive sampling strategy is useful for the researcher to take control of developing samples to meet the research aim and

objectives. It is noticeable that it is not necessary to choose samples from all groups from the chosen context because representativeness is not the primary goal of a qualitative case study research. Including some element of snowball sampling is also useful because interviewees can shed light on context and are able to suggest other appropriate candidates for interviewing. However, these candidates may speak to the same narratives as the one who introduced them. As a consequence, the researcher may face the risk of not having enough rich data. Therefore, to counter this, the combination of purposive and snowball sampling is required.

- Thematic coding analysis and discourse analysis: Analysing data by themes is useful. However, the chosen themes can be different from this study and be dependent upon the research context. Discourse analysis is also useful after thematic coding analysis. Discourses focus on collective meanings and sense-making of actors about transitions, which involve multiple actors, multiple issues in a context; and enable exploration of the interactions between actors and structure.

This study also highlights several phenomena which require further investigation.

This study responds well to the call in applying whole system analysis to investigate transitions of GB's electricity sector. Such transitions are underlined by multiplicity and messiness, and far more complex than both certain academic literature on transitions and the industry claim. To start dealing with complexity, this study suggests a change to a more sophisticated understanding of energy transition processes from a whole system perspective. Further research is needed to find ways to better attend to the multiple and messy aspects of such processes.

In this study, the unit of analysis is the whole GB's electricity sector comprising generation, distribution and consumption. Insights of changes in all these three sub-systems come from actors operating and working in the electricity sector including the government, the regulator, system operator, network companies, energy suppliers, aggregators, consultant companies and so on. However, data were not collected from consumers, prosumers, community energy groups and local authorities. These actors become increasingly important in a consumption sub-system in the future. Therefore, in order to address this, further research could focus on consumers, prosumers, community energy groups and local authorities to investigate energy transitions.

This study also touched lightly on the ethical implications of transition which might be further substantiated with insights from consumers, e.g. in terms of concern over disadvantaged/vulnerable consumers who do not have access to the internet or do not have sufficient demand capacity to shift from one time to another. Further research is needed to understand the implications of transitions for these groups.

A whole system can be broader than a sector, i.e. a socio-technical system which fulfils societal functions. There is a call from both the industry and academia to understand whole system transitions of the *energy* sector which may include electricity, transport and heat sub-systems (c.f. Energy UK, 2016). These three systems are closely connected. Actions in one sub-system may engender changes in another sub-system. For example, decarbonisation of heat through electrification might place an increased burden on the transition of the electricity sub-system. However, research in response to this call mainly focusses on technologies and continues to pay limited attention to the role of actors (McMeekin *et al.*, 2019). This study, while adopting a whole system analysis which takes into account the role of actors, has drawn the boundary around the electricity sector in GB. Therefore, broadening this boundary beyond the electricity sector will be an engaging future research agenda.

This study also identified that more attention should be paid to architectural innovation to complement technologically focussed studies concerned with modular innovation, and hence whole system analysis. There is limited empirical based research exploring architectural innovation, futures and transitions. Nevertheless, this study only focussed on architectural innovation in GB's electricity sector. Hence, further research is needed on architectural innovation in other countries (e.g. German electricity sector, The Netherlands electricity sector) or different sectors (e.g. mobility, food) and subsequent system changes. Studies are also needed on how architectural innovation interact with modular innovation processes.

This study also touched on the notion of power and suggested that power can also be understood as a *productive force* involving interactions between human and non-human elements. This enriches the conventional understanding of transitions which only focusses on actors and how power is transferred between these actors (Avelino and Rotmans, 2009). However, this study did not examine in-depth how these interactions of actors/ elements are exercised or develop a framework to study power in transitions. Hence, future research could fruitfully consider these.

Finally, on 18 November 2020, just prior to thesis submission, the UK Prime Minister announced the Ten Point Plan for a Green Industrial Revolution (Prime Minister's Office, 2020). This plan sets out the ambition of the UK to reach Net Zero climate emission target in terms of different technologies such as offshore wind, hydrogen, nuclear, electric vehicles and CCUS. This plan again reinforces the key findings and conclusions of this study. Policy makers continue to see changes in GB's electricity sector as a technology question/ issue. It is framed as a question of *getting the technology right*, rather than thinking about or changing the system as highlighted in this study. Situated in a broader transitions research literature and providing a critical investigation into energy transitions to low carbon futures, this study offers new insights into the mess and complexities of envisaging and enabling low carbon futures and new sources of energy flexibility in GB's electricity sector.

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Appendices

Appendix A. APPROACH TO TRANSITION STUDIES AND ONTOLOGICAL ROOTS

Table A.1: Ways of thinking about transition (Silveira, 2016). Large format is at: https://www.cisl.cam.ac.uk/resources/publication-pdfs/table-1.pdf

<table>
<tr><th></th><th colspan="3"></th><th colspan="3">Based on the Multilevel Perspective (MLP)</th><th colspan="3"></th></tr>
<tr><th></th><th>The Techno-Economic Approach</th><th>Socio-Ecological Transitions Approach</th><th>Technological Innovation Systems</th><th>Historical co-evolution of social and technological systems</th><th>Active management of on-going transition processes</th><th>Reflexive governance</th><th>Social Practices</th><th>Resilience approach</th><th>Human Geography approach</th></tr>
<tr><td rowspan="2">Focus</td><td rowspan="2">Evolutionary economic theory (after Kondratieff / Schumpeter)

Long-term economic development cycles (40–60 years)

Clusters of new technologies</td><td rowspan="2">History of fundamental patterns of interaction between human society and natural systems

Social organisation of energy and material flows from and into the natural environment

Decoupling human development from resource consumption</td><td rowspan="2">Social and institutional conditions for the emergence of new technologies

Interplay between firms and other actors</td><td colspan="3">Social and technological systems co-evolve through interaction between Micro level(niches), Meso level(regimes) and Macro level (landscape)</td><td rowspan="2">Everyday social practices

Consumer behaviour

Actor networks</td><td rowspan="2">Social-ecological systems as a complex adaptive systems characterised by uncertainty and non-linear feedback loops

Systematic learning approach to the way societies interact and manage the natural environment</td><td rowspan="2">Politics of environmental decision-making across space and time (incl. environmental justice)

Issues of social and ecological context</td></tr>
<tr><td>Historical emergence of transition dynamics (not necessarily towards sustainability)</td><td>Recent and on-going processes of transition, with researchers active in the change process</td><td>Pervasive role of agency and power asymmetries

Issues of legitimacy for government/firms/science</td></tr>
<tr><td>Findings</td><td>Explains how major technological change induces macro-economic cyclical movements, at national level

Identifies five techno-economic eras in last 250 years

Distinguishes different phases within an era

Incremental innovation is important to diffuse technology deriving from disruptive innovation</td><td>Gives consideration to the natural environment in macro-economic development through material flow analysis.

Transitions only occur when there is a structural change in a society's energy flows.</td><td>Identifies key processes that need to run smoothly for the innovation system to perform well

Pinpoints obstacles to radical technological innovation for sustainability</td><td>Patterns of change from below (niches)

Describes strategic niche management</td><td>Multiple sources and patterns of change and how they may be sequenced

Prescribes "transition management" as practice-oriented model (doing by learning/learning by doing)</td><td>Different ways in which power is present at the different levels

Insights on how strategic agency comes about</td><td>Innovation in social practices comes about through networks of people, circulating ideas, and notions of appropriate behaviour</td><td>Resilient social-ecological systems are characterised by adaptability and transformability at multiple scales of social organisation

Role of agents of change and their networks, working simultaneously at different spatial scales</td><td>Beyond national innovation

Interactions between regimes operating across multiple spatial scales (eg the influence of global forces in local decision processes)

Important to strengthen capabilities of local government authorities</td></tr>
<tr><td>Implications for a transition to renewable energy</td><td>Capability of the state is key to extend access of new energy production technology beyond elites</td><td>Technological innovation should target the provision renewable sources of energy</td><td>Government incentives to incumbent business actors are important for the emergence and consolidations of technological innovation hubs</td><td>Emergence of technology as a result of consumer demand, and then embedded in social practices</td><td>Energy transition steered towards a pre-defined goal by government actors and scientists (eg Dutch energy transition)</td><td>More inclusive and conscious decision processes, considering alternatives and sources of uncertainty</td><td>Changes in what is valued results in wholesome behavioural change (new consumption practices)</td><td>Emphasises the importance of social and institutional innovation in the management and governance of renewable energy</td><td>transition unfolds differently according to geographic context and spatial scale

Incentives need to be taylor-made and their impact closely monitored</td></tr>
<tr><td rowspan="3">Critique</td><td rowspan="3">Inability to identify causes behind long-wave cycles (eg over-deterministic view of macro-economic phenomena)

Not able to analyse processes of change at smaller scales of social organisation</td><td rowspan="3">Given its macro-economic focus, it does not consider the role of individual actors, belief systems, culture and political interests (such as those associated with fossil fuel production and consumption)</td><td rowspan="3">Marginalises cultural and social aspects of technology

Unable to understand why obstacles are there and therefore how to remove them

Excessive emphasis on large corporates and government actors</td><td>Does not consider all pressures of change</td><td>Little understanding of how problems are framed and how policy and research priorities are politically and socially constructed</td><td rowspan="2">Not reflexive enough about processes through which power imbalances are replicated

Neglects demand side actors such as consumers and social movements</td><td rowspan="3">May lose track of political and economic incentives and mechanisms behind circulation of ideas (eg government educational campaigns)</td><td rowspan="3">Weaker in the analysis of technological innovation issues

Difficulties in operationalising adaptability and transformability in different contexts

Does not fully explore the role of power asymmetries and how they may preclude adaptability and transformability</td><td rowspan="3">May not fully grasp obstacles for change within government and business organisations</td></tr>
<tr><td colspan="2">Insufficient understanding of the role of power and politics</td></tr>
<tr><td colspan="3">Concept of "levels" leads the observer into hierarchical understanding of reality; insufficient attention to the role of actor networks spanning multiple spatial scales
Spatial bias towards national innovation</td></tr>
</table>

Table A.2: Strengths and weaknesses in SCOT, evolutionary economics and neoinstitutional theory (Geels, 2020).

	Strengths	Less elaborated topics and dimensions
SCOT	**Transitions:** - Interest in shape/design of artefacts and patterns of use - Sophisticated understanding of *emergence* of radical innovation (social networks, learning processes, expectations, circulation, aggregation). **Agency:** - Focus on socio-cognitive processes (*content* of beliefs/meanings, disagreement between social groups; controversies; debates, consensus).	**Transitions:** - Less interest in dynamics after stabilization (diffusion, societal 'impact', overthrow of existing system) - Limited understanding of broader patterns (due to focus on contingency, complexity, local specificity). - Limited link to broader social sciences (due to dominance of micro-interactionism). **Agency:** - Voluntarist tendencies (limited attention for wider structures). - Idealist bias (limited attention for competition, markets, financial resources)
Evolutionary economics	**Transitions:** - Macro-patterns relevant for transitions (trajectories, speciation, radical novelty, replacement, punctuation, extinction). - Micro-dynamics span local practices (variation) and population level (selection, retention). **Agency:** - Deep understanding of 'material' processes (market competition, resources, performance, investment) and knowledge/capabilities (search, learning).	**Transitions:** -Limited interest in technical details (due to primary interest in economic implications of technology for firms/sectors). - Narrow view of selection environment (mainly markets). Limited understanding of institutions (as exogenous regulations). **Agency:** - Limited attention for strategy and cognition/interpretation. - Supply side focus (firms, universities, policymakers); less attention for consumers, wider publics, NGOs.
Neo-institutional theory	**Transitions:** - Relational, processual understandings of institutions. - Recursive interactions between local practices and organizational fields. **Agency:** - Agency in recursive relations to multi-dimensional structures (cognitive, normative, regulatory). - Accommodates struggle, conflict, variation, strategy.	**Transitions:** - Limited focus on technology and 'material' dimensions. - Limited focus on economic processes. - Limited focus on formal, regulatory institutions (due to ideational focus) **Agency:** - Limited focus on technical innovation processes and economic actions. - Some (political) dimensions of power are under-developed.

Appendix B. INFORMATION SHEET AND CONSENT FORM

Information sheet for persons participating in a research project

PROJECT TITLE: EXPLORING THE CHANGING NATURE OF ENERGY FLEXIBILITY IN THE TRANSITION TO A LOW CARBON FUTURE OF GREAT BRITAIN'S ELECTRICITY SECTOR AND THE IMPLICATIONS FOR THE INDUSTRY

My name is Mai Ngoc Nguyen. I am a Research Student at The Open University. I am carrying out research to explore the future of Great Britain's electricity sector. In the transition to a low carbon future of the sector, I am particularly interested in the changing nature of energy flexibility and the implications of this change for the industry. The research is funded by The Open University and CGI.

What is the research about?

I would like to find out how you see GB's electricity sector developing in the future and the role of energy flexibility in the future. I would also like to hear about your organisation and your ideas to identify business opportunities arising from the transition to low carbon futures.

What you and other people tell me will help me to build a picture of a GB's electricity sector's low carbon future. This information will also help Great Britain in general and the electricity sector in particular to prepare for the future. I will use the information you provide for educational and research purposes, including publication.

When will the research be conducted?

The interviews will start from 1 January 2018 and are expected to complete by April 2019.

What will happen during and after the interview?

It would be helpful if you could allow an hour or more so we have time to talk. We can take a break and/or stop the interview whenever you like. If we don't manage to cover everything in one conversation, I will ask if we can meet once more if you don't mind.

Refusal

You can refuse to participate at any point by simply saying so. Participation is voluntary and you can withdraw from the research up until 3 months after the date of interview. You can refuse to answer any question.

Anonymity

What you tell me in the interview will be anonymised. I will not identify you and your organisation when I talk or write about my research.

Audio-recording

I would find it very helpful to audio-record our conversations and then use that to transcribe what you say so I can analyse it. But I will only record the conversation if you agree to this.

How will my data be used?

You will be asked if you consent to the use of your data (including audio recordings) in the research project (e.g. extracts of data, in academic conferences and in published results of the research).

Data used in this way will be analysed by me and discussed with my supervision team.

Data storage

What you tell me in the interview will be stored securely and transcribed (if you allow me to audio-record our conversations). Only the researchers conducting this research will have access to these data. These data will be destroyed after 10 years following the completion of the project, which is estimated to be 31/01/2030.

What if I have other questions?

If you have any queries about the project or your participation in it, please contact me via email: mai.nguyen@open.ac.uk or telephone 01908 858889.

If you have any further queries, please contact Prof Matthew Cook at 01908 655964 or Dr Kevin Collins at 01908 655095.

Consent form for persons participating in a research project

PROJECT TITLE: EXPLORING THE CHANGING NATURE OF ENERGY FLEXIBILITY IN THE TRANSITION TO A LOW CARBON FUTURE OF GREAT BRITAIN'S ELECTRICITY SECTOR AND THE IMPLICATIONS FOR THE INDUSTRY

Agreement to participate

I, (print name)

Agree to be interviewed as part of this research project.

☐ 1. I have had the purposes of the research project explained to me.

☐ 2. I have been informed that I may refuse to participate at any point by simply saying so. Participation is voluntary and I am free to withdraw from the research up until 3 months after today's date. I am free to refuse to answer questions.

☐ 3. I have been assured that my anonymity and that of my organisation will be protected. Neither I nor my organisation will be identified in any outputs of this research.

☐ 4. I agree that the information that I provide can be used for educational or research purposes, including publication.

☐ 5. The interview will be audio-recorded. However, I have the option to decline the recording. I can request destruction of the recording up to two weeks after it is made.

☐ 6. I understand that if I have any concerns or difficulties I can contact Prof. Matthew Cook at 01908 655964. If I wish talk to someone else about this project, I can contact Dr Kevin Collins at 01908 655095.

☐ 7. I assign the copyright for my contribution to the researcher for use in education, research and publication (e.g. an unattributed quote for illustrative purposes).

☐ 8. I have been informed that with my consent the data generated will be stored securely and transcribed (if you allow me to audio-record our conversations). They will be destroyed after 10 years following the completion of the project, which is estimated to be 31/01/2030.

Participant signature: Date:

Researcher signature Date:

Appendix C. INTERVIEW GUIDE

Phase 1 – Interview

WARM UP: 1.1. Tell me about the organisation you work for? 1.2. Tell me about your role in your organisation? What do you do? 1.3. Tell me about the role of your organisation in the electricity sector? CURRENT ORGANISATION AND ENERGY FLEXIBILITY 1.4. Tell me about your business model and energy flexibility in this business model? - How do you make use of energy flexibility in your business model? - What value does energy flexibility create in our business model? - What are the main challenges for your organisation when using energy flexibility?
The first theme that I want to talk about is: 1. CURRENT SITATUTION OF GB'S ELECTRICITY SECTOR AND ENERGY FLEXIBILITY IN THE CURRENT SYSTEM. 1.1. Tell me about the current GB's electricity sector. - How does it work? - Who are key players? - What are the main challenges currently faced by the sector? 1.2. Tell me about energy flexibility in our current system. - How is it achieved? - What is it used for? - What value does it create? - Who are key players? - What are main challenges for energy flexibility?
I am going to move on to the next theme: 2. CHANGES IN ELECTRICITY SYSTEM AND ENERGY FLEXIBILITY IN THE ELECTRICITY SYSTEM 2.1. What changes to the electricity sector do you anticipate? - How will it change? - Which aspects of the sector need to change most? - When will these changes be initiated? - What time horizon do you expect this to happen? 2.2. What changes in energy flexibility do you anticipate in futures? - How will energy flexibility change?

- Which aspects of energy flexibility need to change most? - How soon will these anticipated changes happen? - What time horizon do you expect this to happen?
The final theme that I want to talk about is: 3. FUTURE OF ELECTRICITY SECTOR, FUTURE OF ENERGY FLEXIBILITY AND BUSINESS MODEL INNOVATION 3.1. How will anticipated changes in energy flexibility affect the electricity system? - Which aspects of the system will be affected? - How will it be affected? - How soon will it be affected? 3.2. What is the electricity sector like in futures? - How will it work? - Who will be key players? - What time horizon do you expect this to happen? 3.3. How will the anticipated change of energy flexibility affect your business model? - Which aspects of your business model will be affected? - How will it be affected? - How soon will it be affected? 3.4. How will you make use of energy flexibility in the future? - Which aspects of energy flexibility will be useful to your organisation? - How will you integrate this aspect into your business model? - What value does energy flexibility add to your business model? - What outcomes do you expect?
CONCLUSION: Is there anything else you want to say or you would like to ask me?

Phase 2 – Interview

ENERGY FLEXIBILITY INTERVIEW GUIDE 19/11/18

WARM UP: Can you tell me a little bit about yourself and your organisation?

CHANGE

- Can you tell me about the changes happening in the electricity sector?
- Can you tell me about the main challenges that the electricity sector and your organisation will face over the next 5 - 10y?
- What opportunities might these challenges present for your organisation?
- Can you tell me about any specific innovations that are impacting your businesses?

TECHNOLOGICAL INNOVATION

- Can you tell me about the technological innovations that you are developing? (ask DNOs, Incumbents, New entrants - NE)
- What are the time scales for these?

BUSINESS MODEL INNOVATIONS

- In parallel with these technological innovations, can you tell me about business model innovations that you are developing? (BMI means changes in the way your organisation creates and captures value) (to DNOs, incumbents, NE)
- Prompt: what is the role of this/these BMI in flexibility?

STABILITY

- What are the main barriers for these innovations (specific one)? (to DNOs, incumbents, new entrants)
- We have talked a bit about the things that are changing both technologically or as a business model, what about the things that aren't changing for your organisation and the sector? (to DNOs, incumbents)

POLICY, REGULATION AND MARKET (INSTITUTIONAL ARRANGEMENT)

- What is the role of policy and regulation in this process of change? (Recap of what is changing)
- How does the regulator stimulate innovation? (to regulator)

ORGANISATIONAL CULTURE

- How about internal barriers to develop these innovations/ to change?
- What are new skills and knowledge that are needed for these innovations (specific one)? (to DNOs, incumbents, NE)
- What are the main barriers for developing these skills and knowledge in the future?

INVESTMENT

- How do you see the direction of investment/ investment strategy changing to adopt these innovations? External or internal?
- With these innovations (specific one), what are your main sources of finance? (to new entrants)

CONSUMERS

- How do you see the roles of consumers (both domestic and business consumers) in the electricity sector changing?
- How do you see the relationship with consumers changing?
- Prompt: What is consumers' role in flexibility?

POWER

- Who is driving change in the sector at the moment?
- How will this change in futures?

DISRUPTION

- What may be the major disruptive changes or events in the sector going forward? (to Incumbents, new entrants)
- When is that?

TIME FRAME

- What are the timeframes for these changes (specific one)?
- What will the electricity look like in 2030?
- Prompt: What is the value of flexibility in the futures that you have just described to me?

CONCLUSION: Is there anything else you would like to comment upon now about the future of the sector?

Appendix D. INTERVIEWEES

Phase 1

Interviewees	Interviewees' perspectives	Dates of interviews
I1	Academia	09/02/2018
I2	Academia/ Regulation	26/02/2018
I3	Industry commentator/ Investor	09/04/2018
I4	Distributed asset business/ Transmission and distribution companies	30/04/2018
I5	Industry commentator/ Regulation	23/05/2018
I6	Industry commentator/ Whole-sale market	23/05/2018
I7	Incumbent energy supplier/ Academia	11/06/2018

Phase 2

Interviewees	Interviewees' perspectives	Dates of interviews
I8	Transmission and distribution companies/ Whole sector	12/11/2018
I9	Transmission and distribution companies/ Market	12/11/2018
I10	New entrant energy supplier/ Home	04/12/2018
I11	Incumbent energy supplier/ Trader	13/12/2018
I12	Energy supplier	21/12/2018
I13	Government/ Government agency	10/01/2019
I14	Industry commentator/ Network	15/02/2019
I15	Transmission and distribution companies	27/02/2019
I16	Government	06/03/2019
I17	Government	06/03/2019
I18	New entrant energy supplier	07/03/2019
I19	Trade association	18/03/2019
I20	Industry commentator	19/03/2019
I21	Technological innovator/ Investor	04/04/2019
I22	Trade association	05/04/2019
I23	Transmission and distribution companies	08/04/2019
I24	Transmission and distribution companies	07/05/2019
I25	Incumbent from other sectors	08/05/2019
I26	Code administrator	09/05/2019
I27	Aggregator/ Technological innovator	13/05/2019
I28	Government	04/06/2019

Appendix E. INDUSTRIAL CONFERENCES AND SEMINARS

Apr 2017	**Energy UK Parliamentary Reception**
	Westminster Energy Forum – Smart Energy Systems
Jul 2017	**Challenging Ideas – Reshaping Regulation –** Laura Sandys and Dr Jeff Hardy's workshop
	Westminster Energy Forum – Annual Review of UK Energy Policy, Regulation and Industrial Delivery.
Sep 2017	**Energy UK Breakfast Briefing** - The road to a smart, flexible energy system - Accessing the value of new sources of flexibility
Oct 2017	**Westminster Energy Forum** – Annual Review of UK Energy Infrastructure, Innovation and Investment.
Nov 2017	**Department for Business, Energy and Industrial Strategy (BEIS)** – Smart Meter Data conference
Dec 2017	**Westminster Energy Forum** – Smart Power Transitions
Jan 2018	**Westminster Energy Forum** – Delivering the UK's integrated Low Carbon Power and Transport Future
Mar 2018	**The Network of Early Career Researchers in Sustainability Transitions (NEST) 3rd conference** – New Frontiers in Sustainability Transitions
Apr 2018	**Westminster Energy Forum** – Smart Cities
May 2018	**CGI Central Market Debate – Unlocking flexibility through market facilitation**
Jul 2018	**Annual BSC Meeting and Elexon Seminar 2018** – Supporting Change and Innovation.
Sep 2018	**Energy UK Breakfast Briefing - Realising the consumer value of flexibility**
	British Institute of Energy Economics (BIEE)'s 2018 research conference – Consumers at the heart of energy system
Oct 2018	**Westminster Energy Forum** – Annual UK PowerGen and Network review; and the context of the energy transition**.**
	Energy UK Annual Conference
Nov 2018	**Westminster Energy Forum** – With Oil and Gas UK - The Future of the UKCS: Vision 2035 and the context of the UK's Clean Growth Transition
	Introducing Elexon workshop
Dec 2018	**Launch event – Redesigning the regulation** – Laura Sandys
Jan 2019	**Westminster Energy Forum** - Annual Review of UK Nuclear Policy, Regulation & Markets

Mar 2019	**Westminster Energy Forum** – An Integrated Approach to Energy, Sustainability & Climate Resilience
Apr 2019	**Westminster Energy Forum** – Evaluating the Potential of the UK's Renewable Energy Sectors in pursuit of UK Carbon Targets and key UN Sustainable Development Goals
May 2019	**British Institute of Energy Economics (BIEE)'s Lecture** – Future of Energy – Shell
Jul 2019	**Westminster Energy Forum** – Annual Review of UK Energy, Climate & Sustainability Policy
Oct 2019	**Westminster Energy Forum** - Energy and Climate Strategies for Cities
Jan 2020	**Westminster Energy Forum** - Annual post-COP Review - Climate Uncertainties & Strategic Risks